DOCUMENT RESUME

ED 237 361 SE 043 575

AUTHOR	Froehlich, Walter
TITLE	Spacelab. An International Short-Stay Orbiting Laboratory.
INSTITUTION	National Aeronautics and Space Administration, Washington, D.C.
PUB DATE	Oct 83
NOTE	89p.; Colored pages are of marginal legibility.
PUB TYPE	Reports - Descriptive (141)
EDRS PRICE	MF01/PC04 Plus Postage.
DESCRIPTORS	Astronomy; *Biological Sciences; Design; Facilities; *Physics; Science Education; Science Equipment; *Science Experiments; *Science Laboratories; *Scientific Research; *Space Sciences
IDENTIFIERS	*Spacelab

ABSTRACT

Spacelab is a facility which enables scientists and engineers to go into space for in-orbit research studies. For the 10 European nations that designed, constructed, and financed Spacelab jointly through the European Space Agency and for the National Aeronautics and Space Administration, which designed, constructed, and financed the Spacelab ground facilities and manages the Spacelab flights, this is the culmination of history's largest and most comprehensive multinational space project. Provided in this document is information on: (1) the nature of Spacelab; (2) interior design, equipment, and facilities; (3) Spacelab crew; (4) materials science and space plasma physics experiments; (5) experiments in the life sciences, astronomy and solar physics, and atmospheric physics and earth observations; (6) activities involved in a typical day aboard Spacelab; and (7) Spacelab's birth, impact, and future. (Text material is supplemented by color photographs and diagrams.) (JN)

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Spacelab

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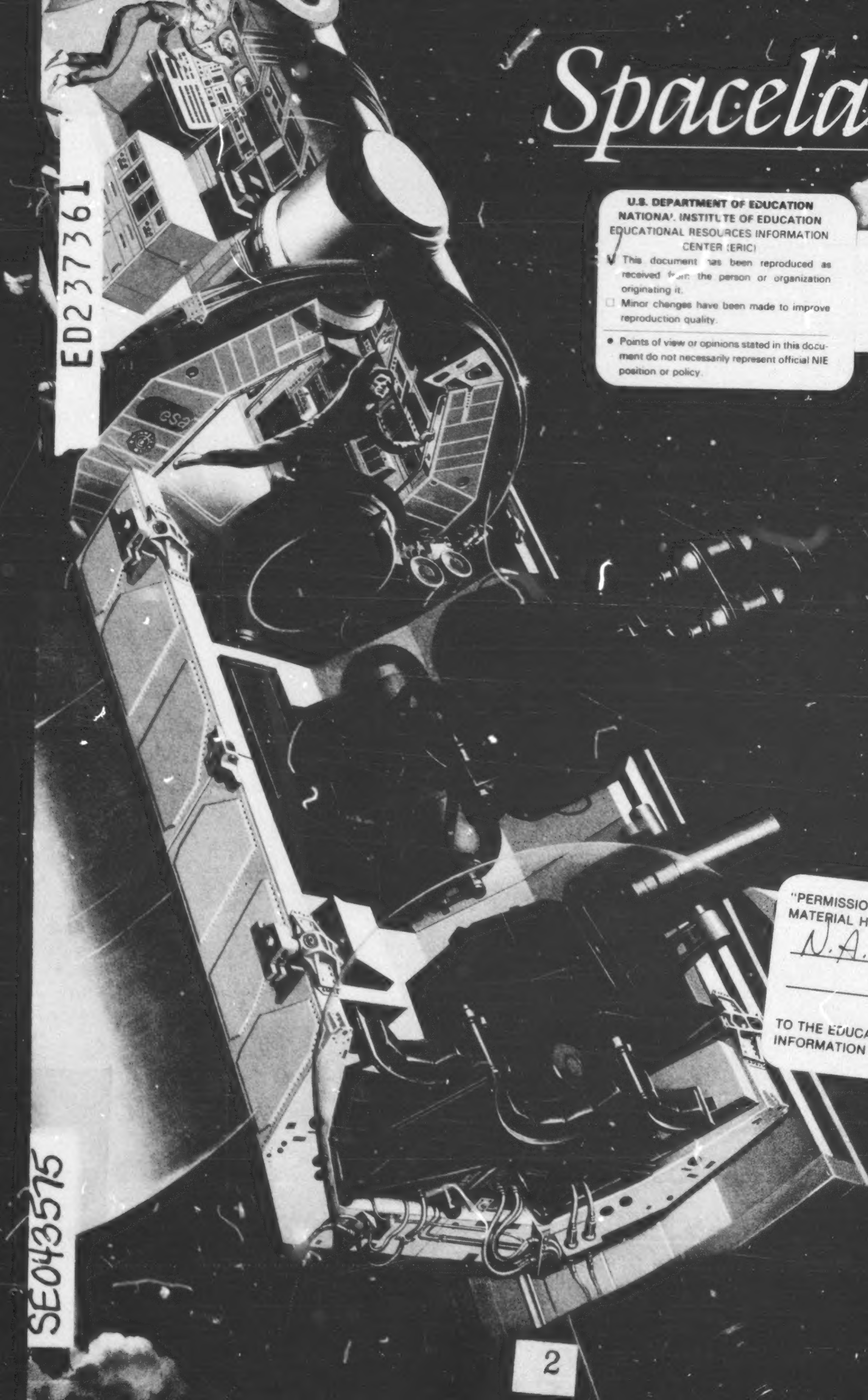

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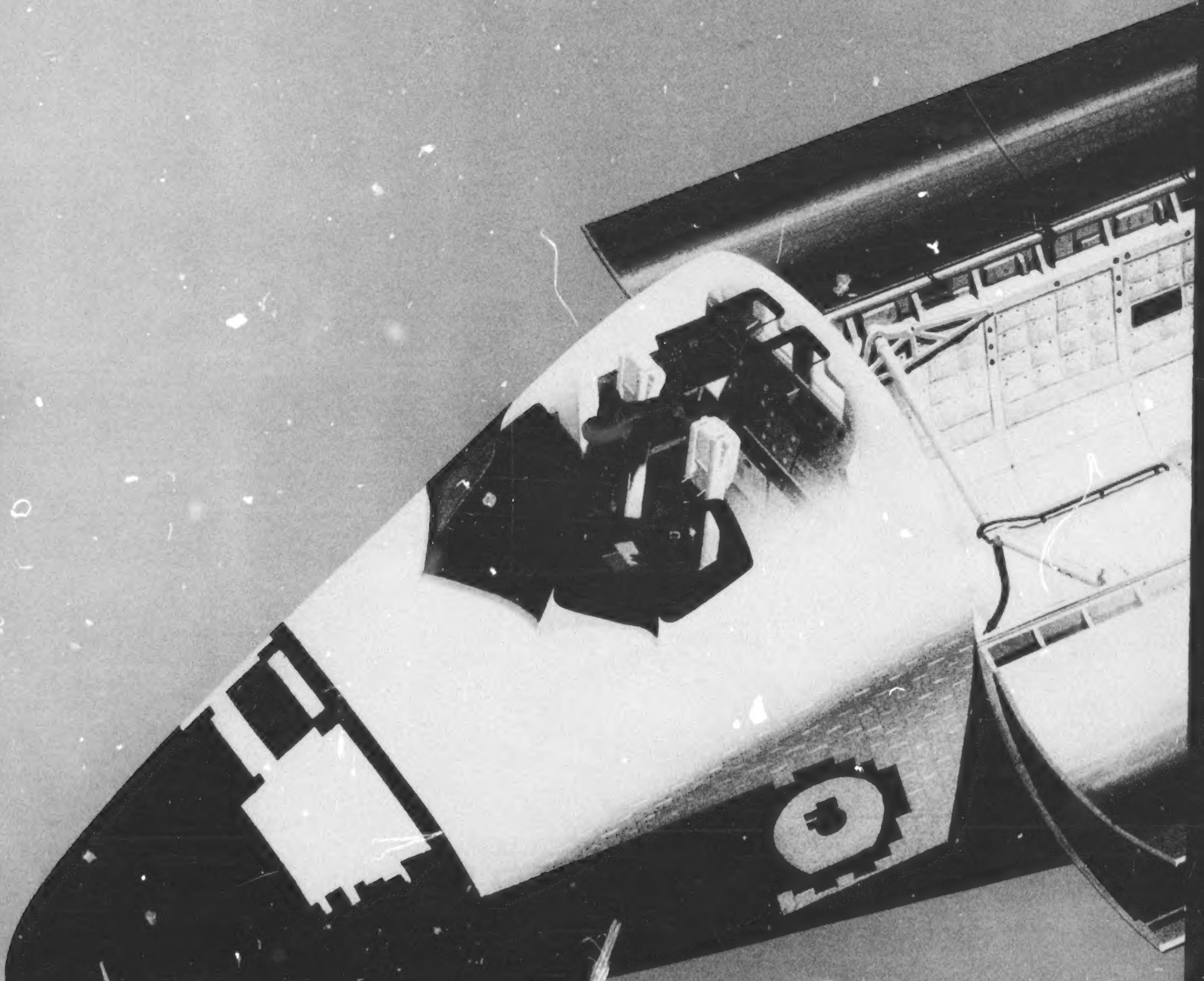

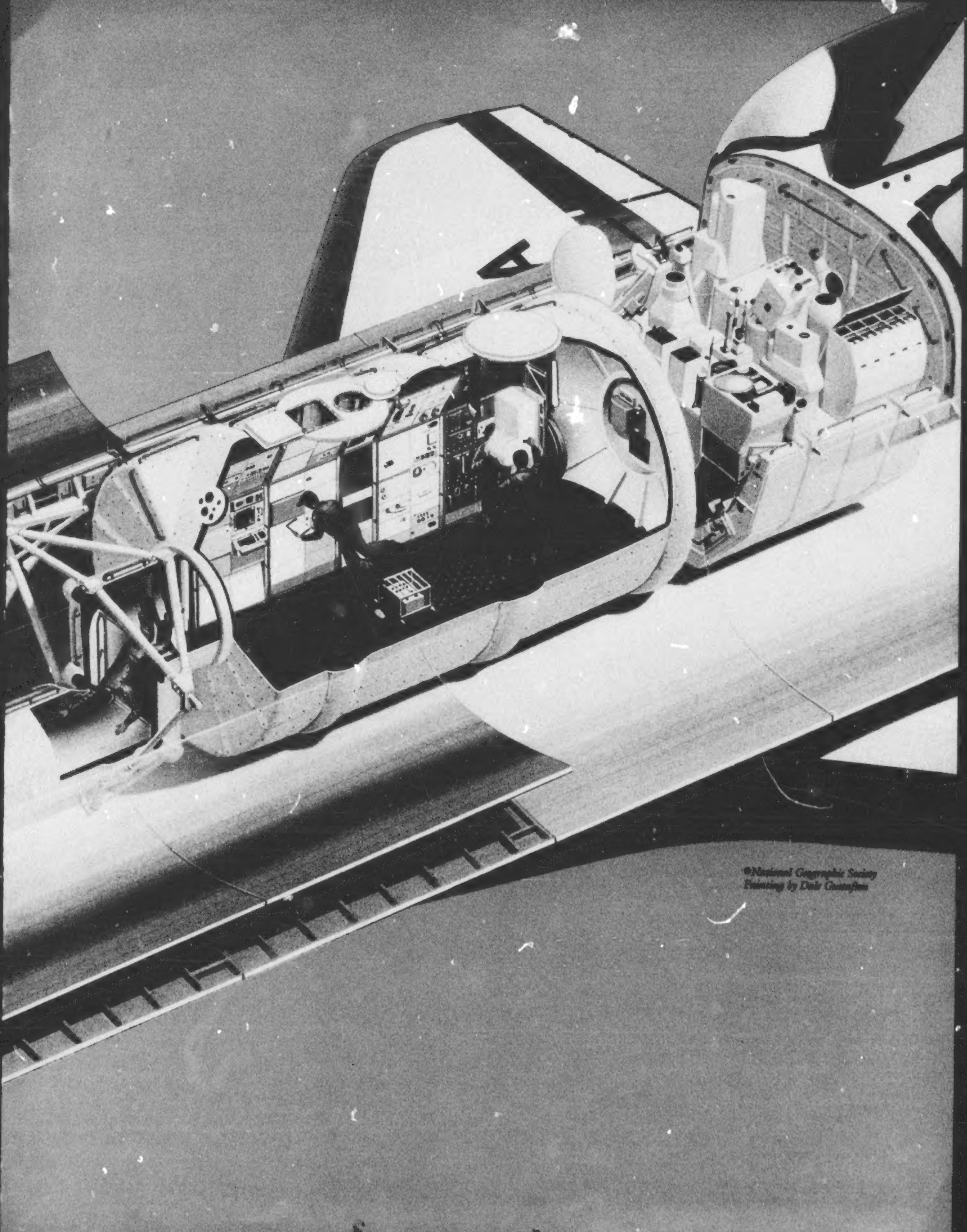

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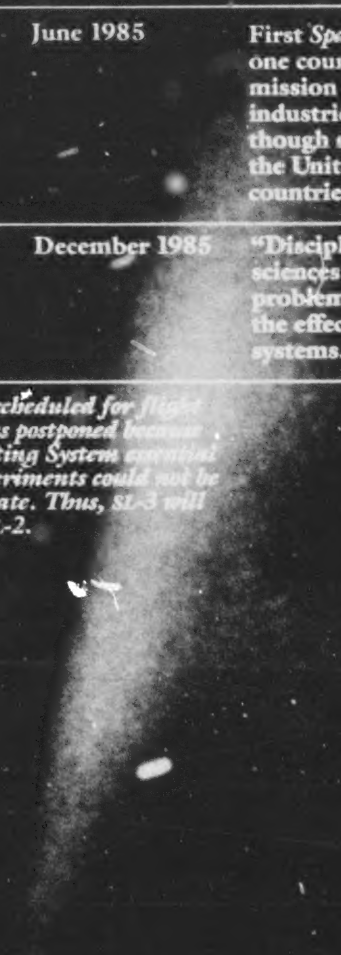
Spacelab *Scheduled Early Flights*

Flight Name & No.	Shuttle Flight Number	Tentative Launch Date	Type of Mission
SPACELAB 1 (SL-1)	STS-9	October 1983	Test flight for *Spacelab* systems. "Multidiscipline mission" with large variety of science and technology experiments.
SPACELAB 3 (SL-3)	STS-18	September 1984	Configuration as in *SL-1* with experiments in materials processing, space technology, life sciences, and astrophysical and environmental observations.
**SPACELAB* 2 (SL-2)	STS-24	March 1985	Second test flight for *Spacelab* systems. "Multidiscipline mission" with pallets only (no habitable module), specializing in astronomy and solar and plasma physics.
D-1	STS-28	June 1985	First *Spacelab* flight entirely purchased by one country. West Germany reserved this mission for use by its universities and by industries and other research institutions, though some experiments will be carried for the United States and several other European countries under special arrangements.
SPACELAB 4 (SL-4)	STS-35	December 1985	"Discipline mission" dedicated to life sciences with 24 experiments on biomedical problems associated with space flight and the effects of near weightlessness on living systems.

**SL-2 was originally scheduled for flight ahead of SL-3, but was postponed because the Instrument Pointing System essential for this mission's experiments could not be ready at an earlier date. Thus, SL-3 will take place ahead of SL-2.*



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U.S. Government Printing Office
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Spacelab

An International Short-Stay Orbiting Laboratory

by
Walter Froehlich

The 10 European nations that jointly designed, built, and financed *Spacelab* through the European Space Agency (ESA):

Austria, Belgium, Denmark, France, West Germany, Italy, the Netherlands, Spain, Switzerland, and the United Kingdom. The U.S. National Aeronautics and Space Administration will manage *Spacelab* flights.

NASA
National Aeronautics and
Space Administration

EP-165

"If the Shuttle itself embodies all that is bold and dynamic in the American character, Spacelab *symbolizes the unity and determination of free Europe... The knowledge* Spacelab *will bring back from its many missions will belong to all mankind..."*

Vice President George Bush at the ceremony for *Spacelab*'s arrival from Europe at the Kennedy Space Center in Florida, February 5, 1982.

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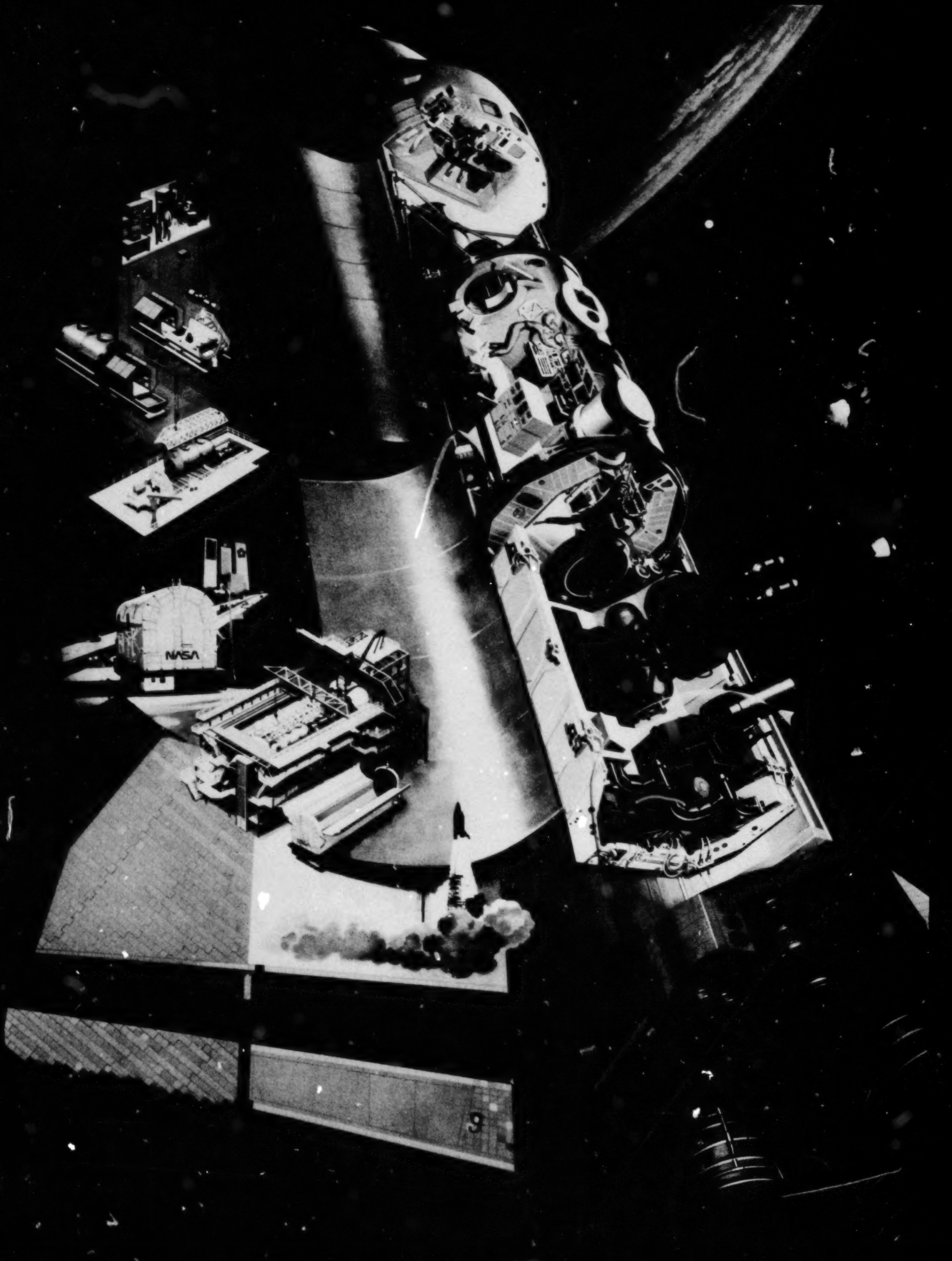

NASA

Introduction

In the orderly ladderlike progression of space exploration, the next logical rung is *Spacelab.* In the early 1970s when decisions for the post-Apollo future of the U.S. space program reached their crucial phase, an emerging need was apparent:

Once the reusable, heavy-lift American space transportation system called the Space Shuttle entered full service in the 1980s, it would drastically alter the ways American satellites are launched. Most one-time-use-only rockets would disappear. Taking their places, the Shuttle would carry the satellites into space and launch them into orbit. But the changes in scientific space research would be even more drastic. Research could be vastly increased because of the Shuttle's ability to carry heavy loads into space. Moreover, the Shuttle would be able to bring heavy cargoes back to Earth. Heretofore this was impossible. What would be needed for taking full advantage of these new opportunities was a versatile facility that would permit scientists themselves to engage in observations and conduct experiments of increasing scope and complexity aboard the Shuttle in space. That envisioned new facility would permit them to do so easily, comfortably, and at low cost, because they could reuse their equipment again and again.

Scientific research in space, though spectacularly successful, had been extremely expensive, partly because of the need to build new research equipment for each flight. Also this was true because of the requirement to design experiments to meet stringent limitations of weight, size, electric power, and environmental conditions.

At the beginning of the 1970s Western European space officials were considering strategies to involve their continent in manned space flight without having to start an extremely expensive program of their own. They accepted an American invitation to participate in the NASA manned space program. They agreed to design, build, and finance the needed research facility for the Space Shuttle. The facility, later to be called *Spacelab*, would be financed and built jointly by 10 European nations through the European Space Agency (ESA) in close cooperation with the National Aeronautics and Space Administration (NASA). NASA would assist with design concepts and provide all needed ground facilities, Shuttle interfaces, and crew training. From the point of view of NASA, with its own resources strained by Shuttle development costs, the European partnership held the promise of a much-sought contribution to the American space transportation system.

After spending 10 years and $1 billion at their complex task, the 10 participating European nations completed *Spacelab*. The United States spent another half-billion dollars to purchase a second *Spacelab* from Europe and for the promised Shuttle interfaces, ground and operational support, and personnel training.

By coincidence, *Spacelab*'s first flight late in 1983 comes only shortly after the 25th anniversary of NASA's founding on October 1, 1958. Conceived and built during the first 25 years of NASA's existence for service during the second 25 years, *Spacelab* marks a dividing line between the first and second quarters of a century of the U.S. space exploration program.

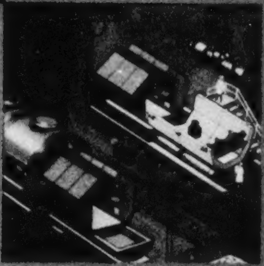
Spacelab was planned and constructed to serve as a suitable host for significant scientific research and technological development. As intended by its European builders and by its American operators, this new facility will serve scientists from many nations and in many scientific disciplines and technological specialties.

Spacelab is the outgrowth of steady evolution of space technology. It enables scientists and engineers to go into space for in-orbit research with their own hands and eyes—with instruments they have designed and built.

This publication summarizes what *Spacelab* is, what it does, how it came to be, and what its users expect from it.

W.F.
October 1983

“Spacelab *represents a major investment on the order of one billion dollars from our European friends. But its completion marks something equally important: The commitment of a dogged, dedicated, and talented team drawn from* ESA *Governments, universities and industries who stuck with it for a decade and saw the project through. We are proud of your perseverance and congratulate you on your success.*



“We are looking forward to the launch… and, looking beyond that launch, let us endeavor to continue to work together in the same spirit of cooperation and mutual support that brought us together today.”

James M. Beggs, NASA Administrator,
at the ceremony for *Spacelab*’s arrival
from Europe at the Kennedy Space
Center in Florida, February 5, 1982.

CHAPTER 1

What Is Spacelab?

It is one hour after the familiar flame and thunder of liftoff. The puffs of exhaust and vapor trails have long since dissipated at the Kennedy Space Center in Florida. The United States Space Shuttle's Orbiter now floats serenely in weightlessness on the opposite side of the Earth, 250 kilometers (155 miles) above the Pacific Ocean.

The crew of six—the commander, pilot, two mission specialists and two non-career astronauts called payload specialists—begin preparations for the scientific work assigned to them on this nine-day flight.

At a console facing the rear wall of the Orbiter's upper crew compartment—the aft flight deck—a mission specialist flips switch R-13, marked "Payload Bay Doors," into the on position. This sets off a 190-second computer-controlled sequence of latch retractions. The huge clamshell doors extending the full length of the bus-size cargo bay swing wide open, revealing its contents.

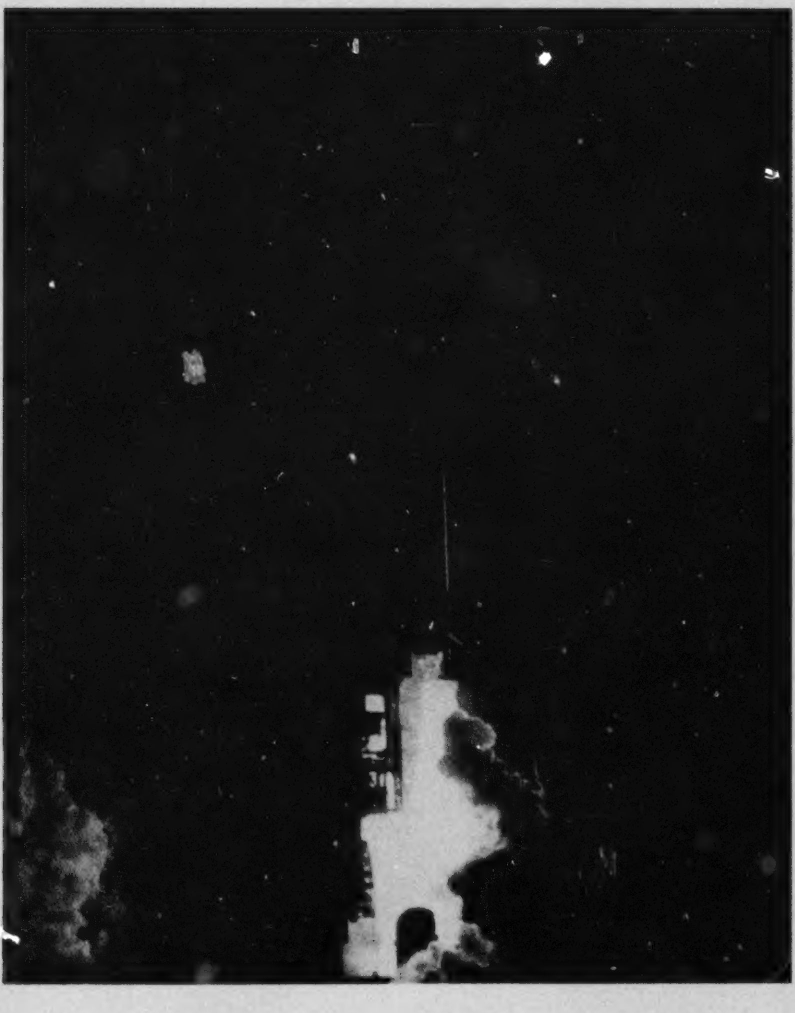
As crew members look through the two aft flight-deck windows into the cargo bay, they see a strange collection of structures as if taken from a frame of a fantasy film.

Resembling a Z-shaped tube, an aluminum tunnel one meter (3.3 feet) in diameter runs from the back wall of the lower crew compartment (mid deck) toward the middle of the cargo bay.

The tunnel connects with the first of two joined cylinders, segments jointly called the module, near the cargo bay's center. Behind the module, not visible to the crew from their windows, rests a U-shaped form, called a pallet, which like the module fits snugly into the 18-by-4.6-meter (60-by-15-foot) cargo bay. Mounted on the pallet are antennas, telescopes, and other sensors.

This odd-appearing assemblage is one configuration of *Spacelab*, the new $1-billion European-built, NASA-operated spaceborne science laboratory.

Within an hour or two, one of the two payload specialists and one of the mission specialists float from the mid deck through the tunnel into the module. They begin operating some of the many research instruments installed there. From controls inside the forward segment of the module they operate instruments mounted on the U-shaped pallet. *Spacelab* has now come alive and is at work!



Project Involves Many Nations

Ten years in the making, the most versatile research facility ever sent into space is now in action. For the 10 European nations that designed, constructed, and financed *Spacelab* jointly through the European Space Agency (ESA) and for NASA, which designed, constructed, and financed the *Spacelab* ground facilities and manages the *Spacelab* flights, this is the culmination of history's largest and most comprehensive multinational space project.

During the next several days the payload specialists and mission specialists will use instruments inside *Spacelab* to carry out a variety of scientific and technological investigations. *Spacelab* is expected to be a frequent passenger inside the Shuttle's cargo bay in the years ahead, through the remainder of the 1980s and into the 1990s.

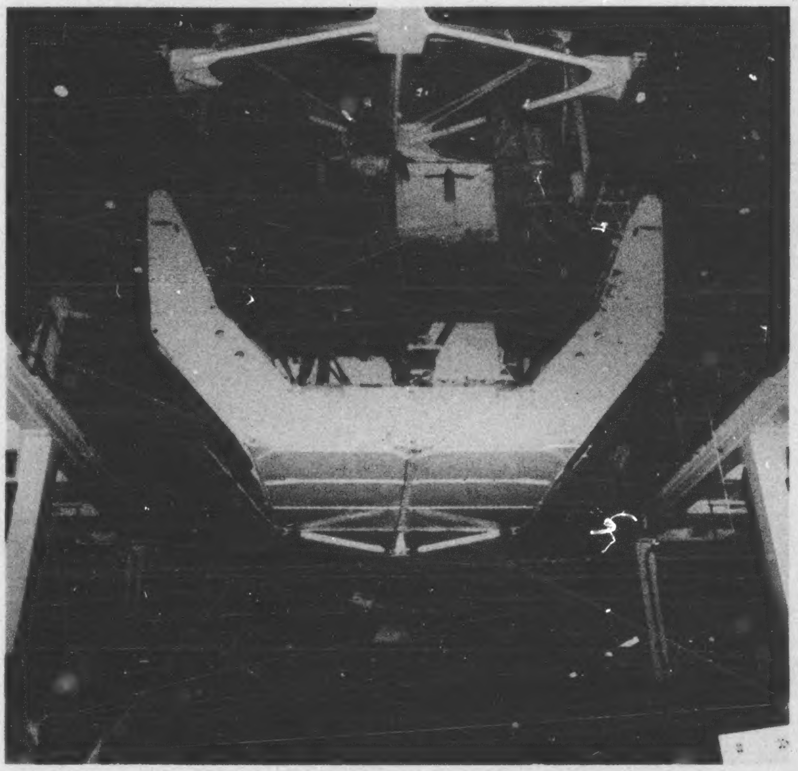
Whenever *Spacelab* is aboard, it is an integral part of the Orbiter, firmly attached inside its body.

Some *Spacelab* flights will be "dedicated missions" on which the Orbiter cargo bay is completely devoted to *Spacelab*—no other loads are carried. Other flights will be "mixed cargo missions" in which *Spacelab* occupies only part of the cargo bay, sharing it with other cargo, such as satellites to be launched from the Orbiter during the flight. Some *Spacelab* flights will be devoted to one scientific discipline only and will be called "discipline missions." The *Spacelab* system lends itself to orbital research in virtually all scientific specialties and technological fields. Flights carrying experiments of more than one scientific discipline are called "multidiscipline missions."

On a discipline mission devoted to astronomy and space physics, payload specialists trained in this science team with mission specialists to operate instruments installed on a pallet. They examine space phenomena, such as the behavior of electrified gases, called plasmas, ejected by the Sun and now trapped above the Earth. On a mission devoted to Earth sciences, the commander and pilot maneuver the Orbiter into an inverted position—so that, as seen from the Earth, it is flying upside down. The payload and mission specialists are thus positioned to use their *Spacelab* instruments to examine Earth's atmosphere, land, and oceans. On missions dedicated to life sciences, physicians and biologists observe the impact of prolonged weightlessness on the crew and on plants and microbes. On missions dedicated to materials technology, specialists in alloys, crystals, ceramics, glasses, and pharmaceutical substances investigate processes observable only in weightlessness.

Early Benefits Possible

Some *Spacelab* experiments—particularly those in materials and pharmaceutical processing—hold high promise of early benefits. Others, like the astronomical observations and plasma investigations, are of immediate interest mainly to scientific specialists. All *Spacelab* work is meant to enrich the human storehouse of knowledge. *Spacelab*'s only assignment is to help increase our understanding of natural laws and to put this knowledge to work for human progress and betterment.



The pallet for SL-1, fully loaded with instruments, undergoes tests before its installation in the Orbiter's cargo bay.

Spacelab is ***not*** a spacecraft but rather a laboratory for use in space. More precisely, *Spacelab* is a set of components which can be arranged in different combinations—or "configurations"—to form a laboratory and observatory tailor-made to the needs of each flight's research objectives. In all its

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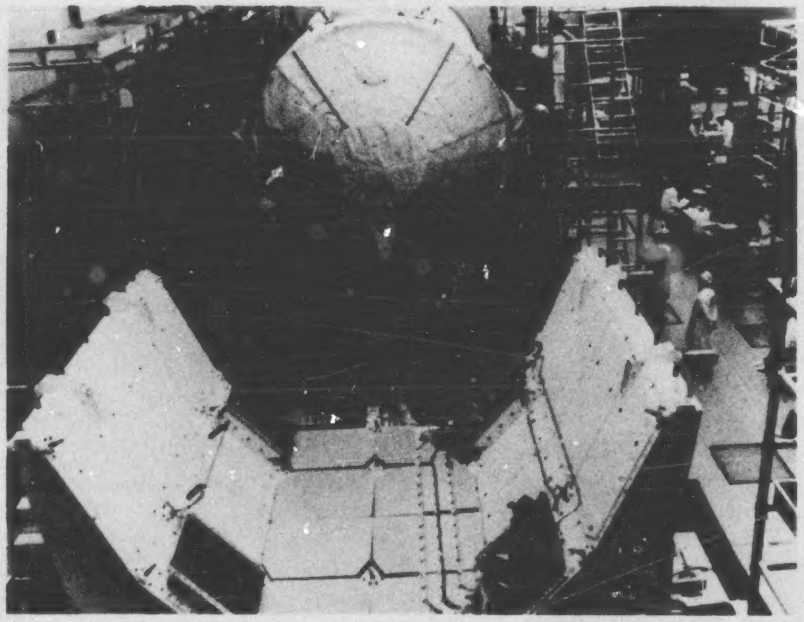
configurations *Spacelab* remains solidly anchored to its host and carrier, the Orbiter, for the duration of the mission.

Spacelab makes possible the transfer of new sophisticated apparatus and high-technology laboratory instruments into Earth orbit. In achieving this feat engineers have come up with many imaginative solutions to the problems of operating in space.

Names used in describing *Spacelab* components and the equipment housed in them tend to be much less glamorous than the items themselves. The cylindrical segments—truly ingenious engineering feats—are prosaically dubbed habitable modules.

Each segment is 2.7 meters (9 feet) long and 4 meters (13 feet) in diameter. They are made of aluminum alloys covered with a thick blanket of multilayered insulation.

The forward segment, which contains controls and monitoring equipment in addition to research instruments, is called the core segment. The aft segment, carrying only research instruments, is called the experiment module. When joined, these two cylinders are simply called the long module. Alone, the core segment is also called the short module.



Module and pallet are readied for SL-1.

Shirt-Sleeve Conditions Provided

In the long-module configuration the interior of the combined segments becomes a room much like the inside of the passenger cabin of a large jet. Three mission and payload specialists can work there simultaneously, surrounded by research and control apparatus in an almost Earthlike environment. They breathe normal air, wear conventional clothes, and set the temperature and humidity to their own liking. Except for weightlessness, they can do their research almost as if they were in any modern high-technology laboratory in their campus, industrial, or government research centers on Earth.

The far ends of the long module are closed with funnel-shaped "end cones." The tip-to-tip distance between end cones is 7 meters (23 feet).

The U-shaped pallet in the rear of the cargo bay serves as a base for research equipment needing a more open view than is feasible from the module, or requiring direct exposure to the radiations and vacuum of outer space.

A pallet weighs 1,200 kilograms (2,650 pounds), is 4 meters (13 feet) wide and 3 meters (10 feet) long, and can support a ton of instruments for each meter of its length—about 3 tons altogether if evenly loaded. With its instruments, the pallet becomes a scientific observatory—for studies in astronomy, space physics, and Earth sciences.

Some pallet-mounted instruments are self-contained and automated and require no human intervention during flight. Others need to be turned on and off, guided, or adjusted—from controls inside the core module, from the aft flight deck, or remotely from the ground by radio command.

Eventually, when all components for two complete *Spacelab* sets are delivered from Europe, NASA will have 2 core modules, 2 experiment modules, 10 identical pallets, and various items of auxiliary hardware.

Many Configurations Possible

Which of these components are used on a flight depends on the research objectives and equipment needs of the mission.

Deciding on the mission configuration and which components to use resembles the problem of a Broadway theatrical producer who must select, together with his director and other specialists, the right combinations of lights, microphones, and scenery to achieve desired results through three or more acts of a stage play.

When a *Spacelab* mission requires it, as many as two pallets can be installed in the Orbiter's cargo bay behind the long module.

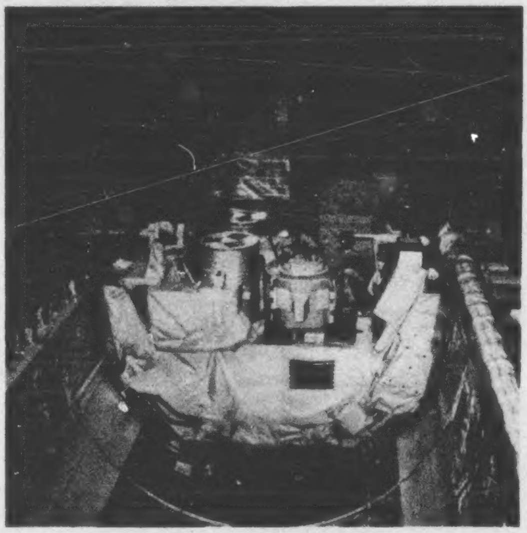
If a mission's needs can be satisfied with only one segment of the module, the core segment would be used. As many as three pallets can be installed behind it.

Or if no habitable module is needed on a mission, any number of pallets up to five can be made to fit, one behind the other, in the Orbiter's cargo bay. Up to three adjacent pallets can be rigidly attached to each other to form a "pallet train"—for equipment too large or too heavy to fit on one or two pallets. When no modules are flown, pallet-mounted instruments are controlled from the Orbiter's aft flight deck or remotely from the ground. Present plans call for the use of six possible component configurations.

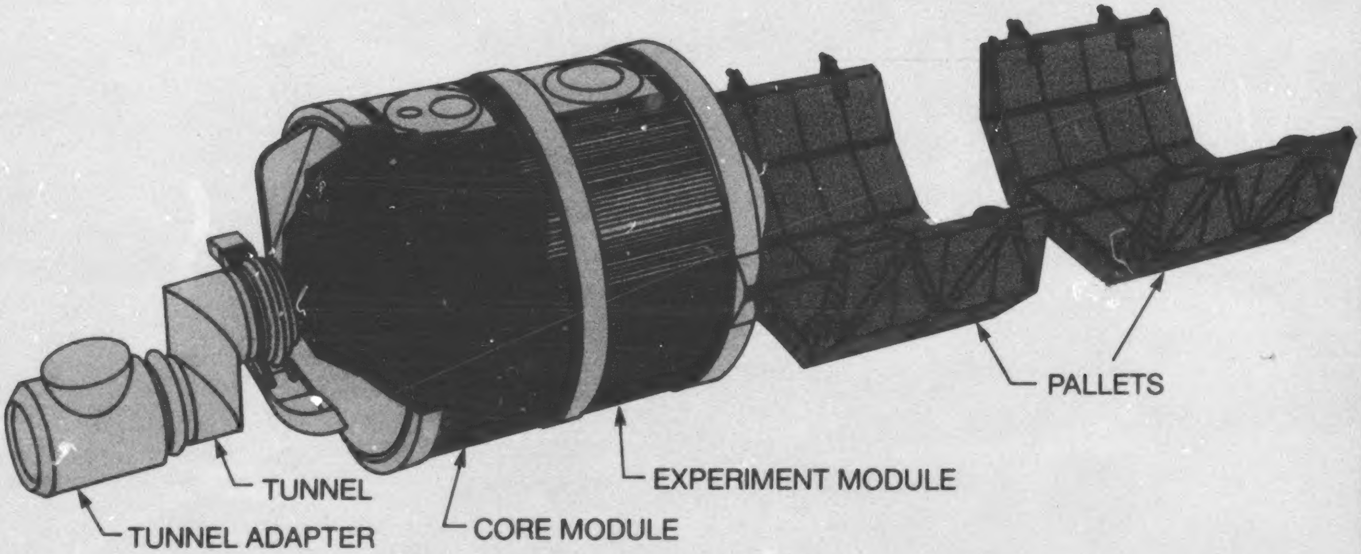
The Orbiter-*Spacelab* combination can provide electric power, thermal control and also data collection, recording, processing, storage and transmission as each instrument may require.

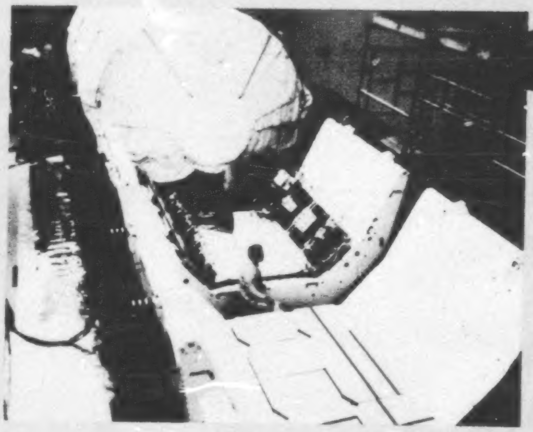
Spacelab takes advantage of new possibilities to widen in-orbit research opened by the Space Shuttle that attained operational status in 1982. *Spacelab* pushes in-orbit research into broader dimensions.

International Partnership—Spacelab's multinational origin introduces an unprecedented international flavor into space research. Never before have so many nations participated in any activity aimed exclusively at improvement of space investigations. The 10 European nations that jointly developed and paid for *Spacelab* delivered the modular laboratory to the United States for use by NASA as an integral part of the Shuttle. NASA, which developed and operates the Shuttle and all the *Spacelab* ground and training facilities, has management responsibilities for all *Spacelab* flights. Nations or institutions may rent all or part of *Spacelab* for one or

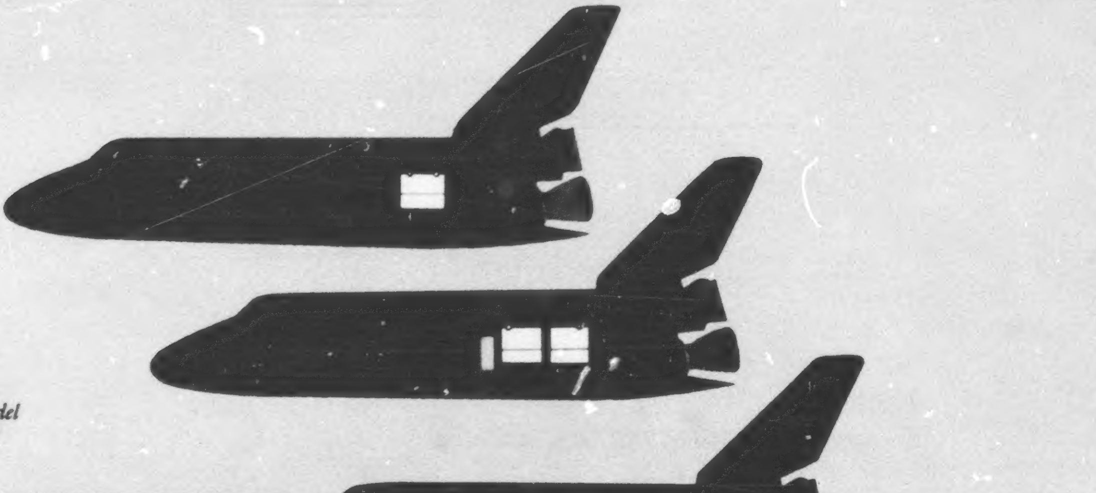


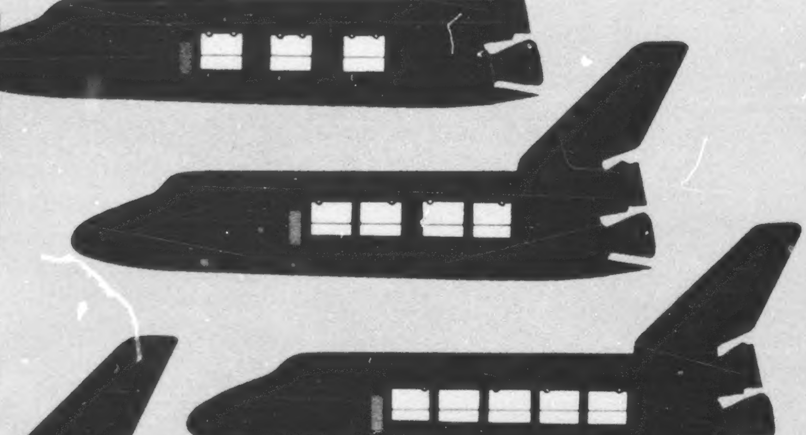
Instrument-laden pallet inside cargo bay gets ready for next mission.

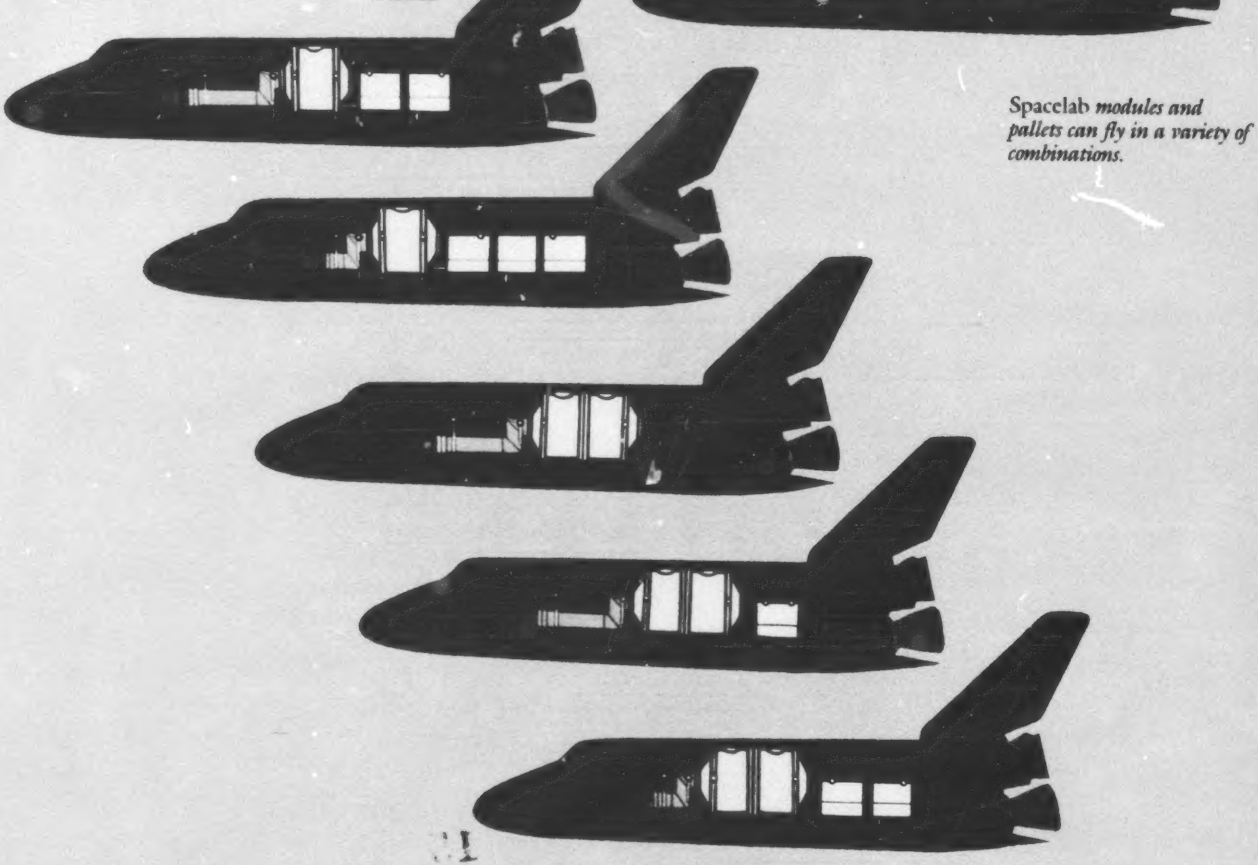




Spacelab *engineering model with U-shaped pallets and long module.*







Spacelab *modules and pallets can fly in a variety of combinations.*

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more flights by paying NASA for the costs of the launch and operation of the mission. These users can then have *Spacelab* outfitted with their own experiments and operated in accordance with their needs. Two nations—West Germany and Japan—are already planning to rent *Spacelab* under this reimbursable arrangement. In cooperative missions no money changes hands, but users share research results. This international aspect of *Spacelab* operations is intended to endure. As planned from the beginning by the contributing European nations and NASA, *Spacelab* will be used for research by experimenters from the United States, Europe, and other countries throughout its service life.

Versatility—The building block approach, or modular concept, of *Spacelab*—the option to employ facilities selectively in a wide variety of configurations—introduces a flexibility never before available to researchers for in-orbit experimentation. Severe limitations in size, weight, power consumption, and data handling traditionally imposed on space experiments are being liberalized by the Shuttle-*Spacelab* combination with its capacity to accommodate a very wide range of research needs.

Returnability and Reusability—Like its carrier ship, the Orbiter, *Spacelab* is returnable from space and reusable. So are the research instruments and specimens aboard. All components of *Spacelab*—the module and pallets and everything associated with them—are returned to Earth.

After the Orbiter's landing, *Spacelab* research instruments and equipment and all biological and materials samples are available for study and analysis by each experiment's investigators. All equipment and instruments can be sent back into space on subsequent flights if desired. Considerable savings are achieved by avoiding the need to replace one-time-use equipment, as was necessary earlier. These and other economies make experiments affordable that were formerly prohibitively expensive.

Scientists in Space—Non-career astronaut scientists, after as little as 100 hours of special training in the intricacies of living in orbit, can travel into space aboard the Shuttle and conduct research using *Spacelab*'s made-to-order research facilities. The skills, knowledge, and judgment of scientific and technological specialists who have not needed to spend several years in astronaut training become available directly for in-orbit investigations in a wide variety of scientific disciplines and technological specialties.

As now foreseen, the frequency of Shuttle flights (2 in 1981, 3 in 1982, and 4 planned for 1983) will gradually increase to perhaps as many as 24 each year—an average of 2 each month in the late 1980s and in the 1990s. One or two flights each year are expected to be "dedicated" *Spacelab* flights, which means that cargo bay space and crew time will be devoted almost entirely to the operation of *Spacelab* and its experiments. (These figures could change with shifts in future budget allocations, national priorities, or investigators' demands for Shuttle and *Spacelab* facilities.)

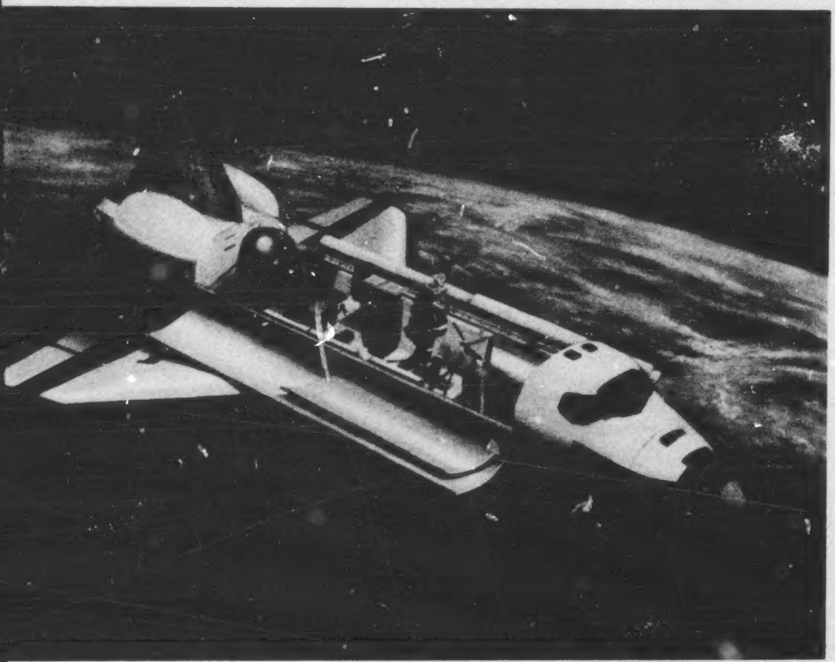
Many other flights with the new Space Transportation System (STS)—better known as Space Shuttle—will carry a *Spacelab* pallet or one or more other *Spacelab* components.

Two Pallets Flight-Tested

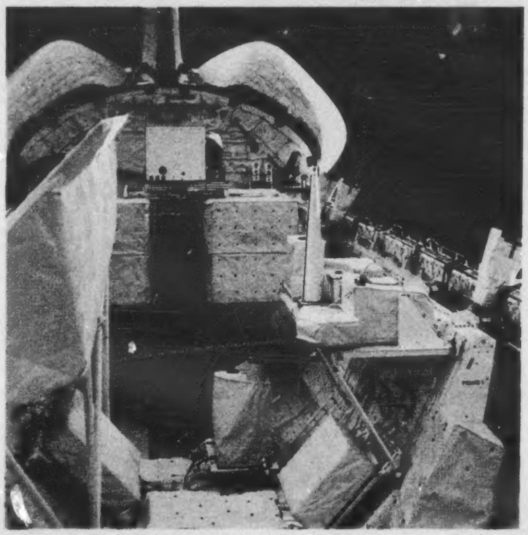
Indeed, the Shuttle already has carried two test pallets into orbit—one late in 1981, and the other in 1982. These pallets, essentially identical to the flight models built for future missions, were sent by the European Space Agency to the Kennedy Space Center in Florida.

Two pallets were on board during the second and third Shuttle test flights—STS-2, November 12 to 14, 1981, and STS-3, March 22 to 30, 1982. These were the first in-orbit tests of any major *Spacelab* elements, also the first times the Shuttle took any scientific research equipment with it into orbit other than for measuring its own flight performance. Remarkably successful research results were obtained with pallet-mounted instruments on STS-2 and -3. The pallets, with their relatively simple electrical power, cooling, and command and control functions proved to be practical and useful.

Five Earth-looking research instruments weighing a total of a ton were mounted on the test pallet aboard STS-2. They were part of a pathfinder research packet called OSTA-1, an acronym denoting that this was an experiment series assembled by NASA's former



SL-2 will be a multidiscipline mission with 13 instruments on three pallets and a special support structure.



Pallet carrying OSTA*-1 experiments is visible with other equipment in cargo bay in this photograph taken in orbit by* STS*-2 crew through flight deck's aft window in November 1981.*

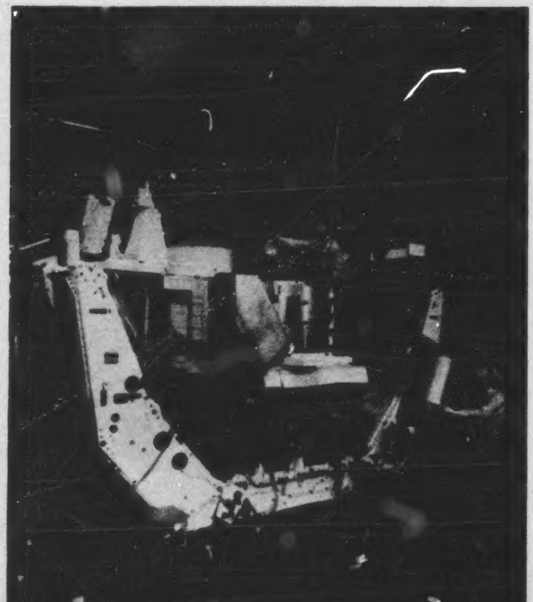
Office of Space and Terrestrial Applications (OSTA). These experiments, typical of the kinds of apparatus pallets are likely to support on future flights, were prototypes designed mainly to calibrate new spaceborne instruments and to determine the effectiveness of new techniques for Earth research from orbital altitudes.

OSTA-1 instruments verified that it is possible with the larger and more powerful instruments mountable on the pallets to locate and identify minerals on Earth, sniff out concentrations of carbon monoxide in the lower atmosphere, survey ocean algae concentrations with great accuracy, use radar for Earth surface and sub-surface mapping and program Earth observation instruments so that they turn themselves on and off automatically as desired, whenever they fly above bare land, vegetation, water, snow, or clouds. This last instrument, called FILE (Feature Identification and Location Experiment), showed that such "smart" sensors can be automated to make their observations only above certain kinds of objects—eliminating unnecessary recording, transmission, storing, and sorting of vast quantities of data unneeded for specific investigations.

Research Introduced Early

The use of spacecraft for scientific research follows a tradition that dates back to the very beginning of the United States space program and has continued without interruption since. The first U.S. satellite, Explorer 1, launched on January 31, 1958, was outfitted with three small research instruments which made the first major scientific discovery in space.

At that time, more than 25 years ago, the United States was eager to place a satellite into orbit as soon as possible to prove that U.S. technology was not trailing that of the Soviet Union. Nearly four months earlier, on October 4, 1957, the Soviets placed history's first man-made satellite, Sputnik I, in orbit. Despite this urgency, U.S. space planners insisted that their satellite serve a purpose beyond merely signaling its presence in orbit. Thus Explorer 1, despite its relatively small size—15.2 centimeters (6 inches) in diameter and 203 centimeters (80 inches) long—and its light weight —14 kilograms—carried a Geiger counter and two micrometeoroid detectors. These proved sufficient to locate radiation belts whose existence until then had only been theorized.



Crammed with instruments, this pallet is prepared for flight aboard STS*-4 in 1982 at* NASA*'s Goddard Space Flight Center in Greenbelt, Maryland. The pallet was aboard the fourth mission of the Orbiter* Columbia*; its instruments carried out experiments in astronomy and space plasma physics.*

New Discovery Named

These phenomena surrounding Earth were promptly named Van Allen radiation belts after the University of Iowa physicist, Dr. James A. Van Allen, who had designed the experiment and analyzed its results.

Explorer 1 was rapidly succeeded by increasingly larger, heavier, equipment-crammed satellites with ever more advanced instruments for astronomy, physics, and Earth survey research.

With the beginning of manned space flight in 1961, science in space took on new meaning. Instead of relying solely on automated, remotely controlled instruments, people could now make their own observations in space and adjust instruments directly. However, early manned spacecraft were small. Essential flight equipment left little room for scientific research instruments. This severely restrained early space science, but in their eagerness to explore the newly accessible regions of space, scientists found ways to do some research while fulfilling astronauts' needs.

In 1961 astronauts Alan Shepard and Virgil I Grissom, the first Americans in space in suborbital flights, and in 1962 John H. Glenn, the first American in orbit, wore sensors on their chests through which physicians on the ground could instantaneously monitor their heartbeats, breathing rates, and other physical parameters during acceleration at launch, weightlessness in orbit, and deceleration during reentry in their Mercury spacecraft.

The two-man Gemini spacecraft completed 10 successful orbital flights within a 20-month period in 1965 and 1966. Each craft's two-astronaut crew had about as much living space to share with each other as is available in the front seat of a compact car.

Three-Man Craft Roomier

The three-man Apollo spacecraft that entered service in 1968 expanded interior living space for astronauts to about the volume of a big station wagon and added considerably to weight-carrying capacity for round trips from Earth to orbit. For the first time in the American space program, it was possible for astronauts to get out of their seats and their pressure suits and move around in their vehicle. In 3 Earth-orbital, 3 around-the-Moon and 6 Moon-landing flights—a total of 12 manned space flights from 1968 through 1975 (one of which was the Apollo Soyuz mission)—plus three *Skylab* missions, the Apollo spacecraft made milestone contributions to nearly every field of science and technology.

Two-man teams of astronaut explorers in the six Moon landings carried out geological field trips on the lunar surface, gathered samples of lunar rocks and soil for return to Earth, and set up geophysical research stations containing a variety of instruments. These units continued to radio data to Earth long after the astronauts had left the Moon.

The Moon flights were the first to take humans away from the direct influence of Earth and showed that they could survive and do useful work on another world.

Apollo Does Extra Research

Scientific and technological research with a manned spacecraft had reached another high point during the period from May 1973 through February 1974. That period included the three manned missions with *Skylab,* an orbital craft the size of a small three-bedroom house—by far the largest spacecraft launched by the United States—and a direct ancestor of *Spacelab.*

Three astronaut crews, aboard three separate Apollo craft, rendezvoused in turn with *Skylab* in Earth orbit, linked their Apollo to *Skylab*'s docking port, and entered and worked inside the orbiting laboratory—for nearly a month in the visit by the first crew, nearly two months during the second crew's stay, and about three months in the third crew's visit. The relatively large size of *Skylab* provided ample interior working and living space and, for the first time, allowed astronauts to work in orbit with bulky equipment, including several large Sun telescopes, furnaces for melting metals in weightlessness, and other apparatus for processing alloys, composites and other substances.

Skylab was *reusable* but not *returnable*. The three crews did, in fact, use it three times, leaving it vacant from 36 to 52 days between visits. It and all other early spacecraft suffered from the disadvantage that nearly everything they took aloft was on a one-way trip. Ability to bring instruments and research samples back to Earth was very limited. *Skylab* eventually fell back into the atmosphere after its orbit decayed and, except for a few pieces of debris which fell on Australia and into the Pacific Ocean, burned to dust and ashes from atmospheric friction. The only *Skylab* objects returned had to be loaded into limited space in one of the visiting Apollo craft with their relatively small payload capacity.

With cargo bay doors closed, Spacelab *is obscured from view, but well-protected from searing heat, during Orbiter's reentry and landing.*

It was Space Shuttle with its ability to bring back to Earth 14,500 kilograms (32,000 pounds) of cargo that made *Spacelab* possible.

Spacelab is designed to exploit the Shuttle's potentialities to the fullest as a vehicle for scientific research.

Spacelab Missions 1 and 2 are verification flights to test and check out *Spacelab*'s systems under differing conditions, using a variety of scientific and technological experiments. The first is a module-plus-pallet configration while the second is a pallet-only configuration. (Actually Mission 3 will precede 2 in the schedule as it is presently drawn.) These first flights and early ones to follow are expected to last from 7 to 10 days each. While mission objectives and the types of experiments change with each flight, procedures for returning home remain unchanged.

Shortly before the end of a *Spacelab* flight, the mission specialists and payload specialists return from the module through the tunnel to the Orbiter mid deck. A mission specialist flips switch R-13 into reverse. The big cargo bay doors close. Latches reengage. The protective doors now shield *Spacelab* from the searing heat and friction of reentry and landing.

Much Data Returns to Earth

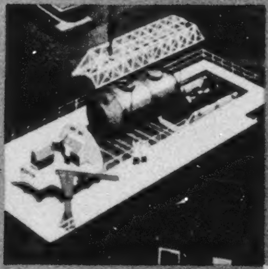
Back on Earth, *Spacelab* is removed from the cargo bay, freeing the Orbiter for other assignments. Films, recordings, biological specimens, and material samples are removed and given to the appropriate researchers for analysis.

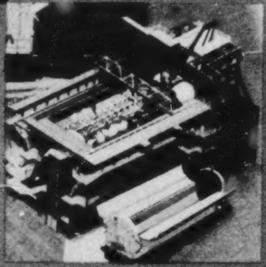
Most of the information generated by research instruments already has been transmitted to Earth during the flight via radio communication links.

The research equipment, like the Orbiter and *Spacelab* themselves, is reusable and can later be sent back into space if desired.

Spacelab's module and pallets are outfitted with new sets of research instruments and supplies. Requirements of the next mission may call for a different configuration of components than was used last. *Spacelab* is reassembled in the chosen configuration and inserted into the cargo bay of one of the orbiters of NASA's Shuttle fleet. The space science laboratory is ready for its next trip into orbit.

“S*tep right in, ladies and gentlemen! Welcome to* Spacelab! *This is the real thing. Not a mockup. Not a replica. The module in which you are standing has flown in space 178 days. Seventy-five Shuttle missions have carried* Spacelab *pallets or modules. This module was used on 20 flights, and it carried crews totaling 126 men and women through 2,848 Earth orbits. In those crews were 83 scientists—71 men and 12 women—who worked as mission specialists and payload specialists and carried out 476 scientific and technological experiments in orbit. Among the many historic discoveries they made was. . . .”*





CHAPTER 2

A Sightseer's Tour of Spacelab

One of the volunteer tour guides at the National Air and Space Museum in Washington, D.C., is speaking. It is near the turn of the century—perhaps 15 years from the first *Spacelab* flight in 1983. One of the two sets of *Spacelab* components—a long module and five pallets and various units of auxiliary equipment—is now part of the Air and Space Museum's permanent "Milestones-of-Manned-Flight" exhibit.

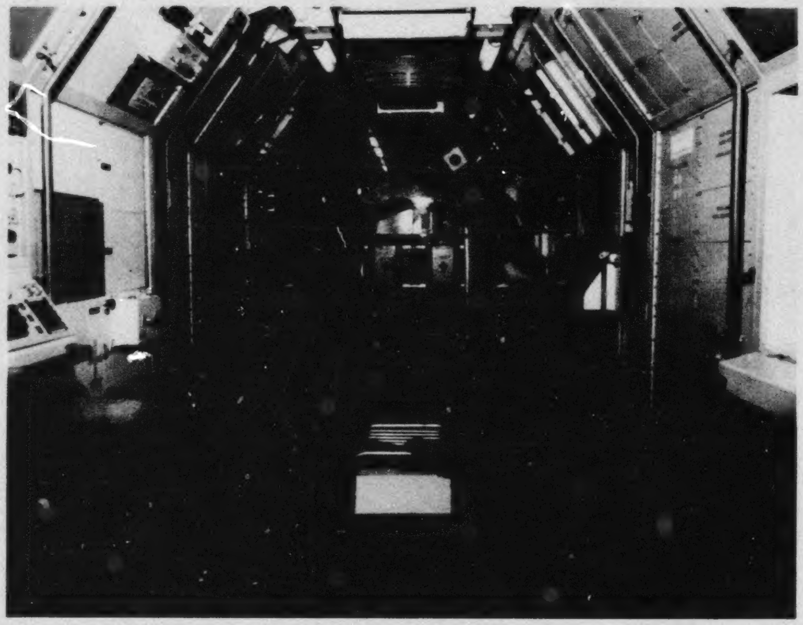
The other identical set of *Spacelab* components joined the permanent collection of a major museum in Europe. In addition to their normal Shuttle use both sets had put in short tours as experimental research and application modules with the U.S. space station launched in the 1990s. The modules, loaded with experiments, were repeatedly taken into orbit aboard the Shuttle and stayed there attached to the space station for periods up to three months. The modules were then returned to Earth by the Shuttle, unloaded, re-equipped with other experiments, and launched once again for more research at the space station.

This scenario is imaginary, of course. Figures given by the fictitious tour guide are merely projections and extrapolations. So are all of the statements about the two sets of *Spacelab*. But if the expectations of the European builders and NASA operators of *Spacelab* materialize, its history may closely parallel this scenario and these figures.

The first *Spacelab*—built and funded in Europe—is complete and ready for service beginning in late 1983. The second *Spacelab* is being purchased by NASA from its European builders and is expected to be ready for service in 1985. Each of these *Spacelabs* is designed for as many as 50 missions.

When these *Spacelabs* are eventually retired to become museum exhibits, they will differ in some important ways from earlier displays of the relics of manned space flight.

Tourists cannot wander into the earliest habitable enclosures flown in outer space—Mercury, Gemini, the Apollo command module, and the Apollo lunar landing module, which were the first U.S. manned spacecraft. All are far too small for sightseers to enter. Most of the units on museum display are sealed, but have transparent walls or windows through which visitors can look inside. *Skylab*, the largest U.S. habitable space enclosure, is big enough so that groups of visitors do walk through it at the National



Training inside a replica of the long module are the payload specialists for the first Spacelab *flight. From left: Dr. Byron K. Lichtenberg and Dr. Michael L. Lampton, both from the United States, Dr. Wubbo Ockels (kneeling) from the Netherlands, and Dr. Ulf Merbold from West Germany. Lichtenberg and Merbold are in the flight crew; Lampton and Ockels are alternates.*

Air and Space Museum's display. But *Skylab* (like the lunar module) was abandoned in space after its usefulness was exhausted. The flight unit is gone. Exhibits are made up of unflown duplicates or mockups.

All of Spacelab Returnable

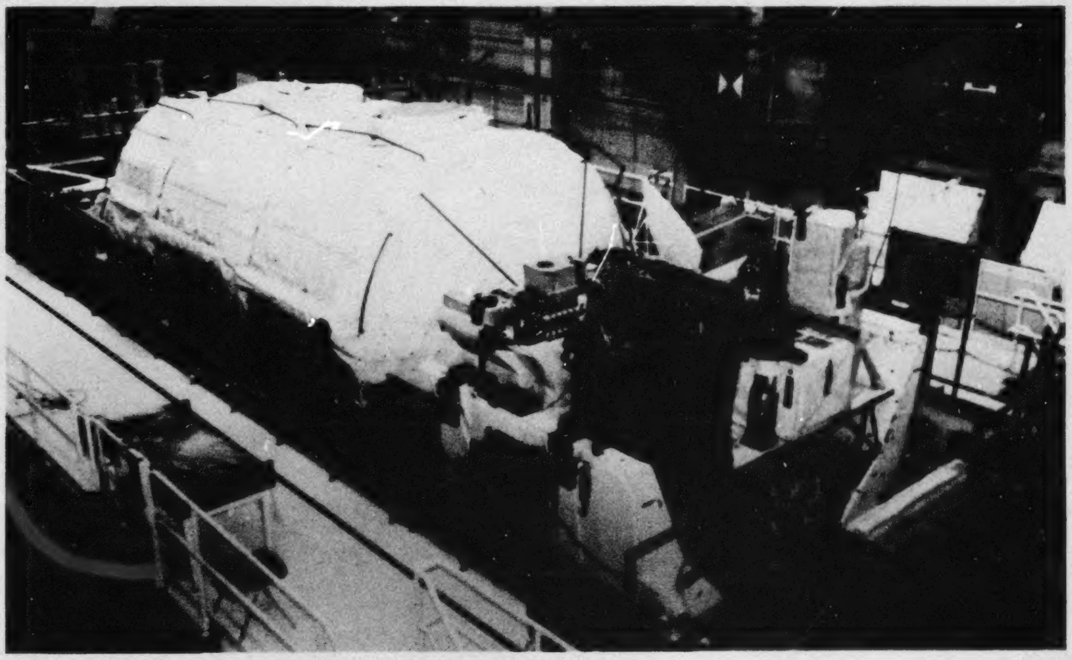
Not so with *Spacelab*. Every part of it—and everything it carries with it—comes back to the Earth after each flight. In the words of the fictitious museum guide, "the real thing" with all its furnishings and auxiliary equipment can go on display once the units are withdrawn from flight duty. There is ample room for small groups of tourists to gather in its interior.

Spacelab's long module—7 meters (23 feet) long and 4 meters (13 feet) in diameter—combines the core and experiment segments and has the dimensions of a medium-size house trailer. Its 5.4-meter-long (18-foot) center aisle is a suitable place for the tour to begin.

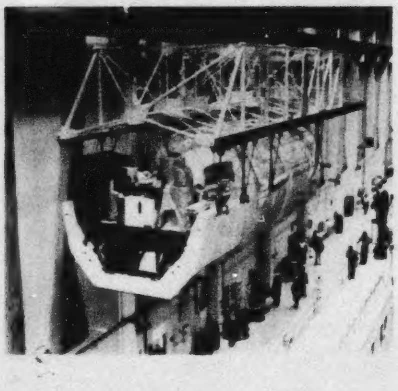
What the museum visitors see from the aisle looks much like the scene in other modern research laboratories: Walls are lined with the standard 48-centimeter-wide (19-inch) laboratory racks containing custom-made instruments and equipment. One sees switches, status indication lights, intercom stations, keyboards, several display screens. There is a workbench for making minor equipment repairs and adjustments. It looks like a lectern and will be used also as a writing desk.

Stowed in racks and overhead ceiling bins, resembling the storage compartments above passenger seats in planes and trains, are common laboratory supplies and utensils—film, magnetic tape, cameras, test tubes, lab cultures, material samples, spare parts, lubricants, and repair tools, including wrenches of different sizes, screwdrivers, knives.

Yet any notion that this is an ordinary laboratory is quickly dispelled. Even



Long module and pallet being readied for loading into the Orbiter's cargo bay at the Kennedy Space Center in Florida.

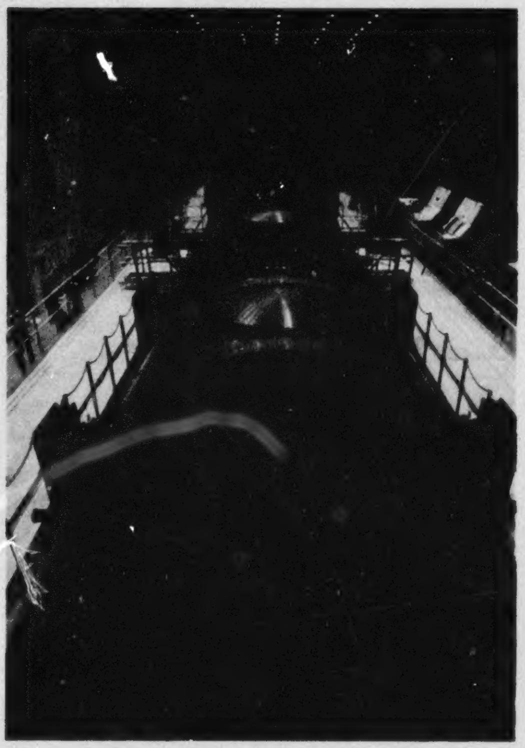


sightseers unfamiliar with research installations notice that this is an unusual facility. Handrails are within easy reach from any location. So are foot restraints. Items in the stowage racks are surrounded by foam filler. Test tubes are closed to keep fluids from floating away. There are no doors. The entrance is a tunnel (which has been removed along with the end cone, to permit tourist access).

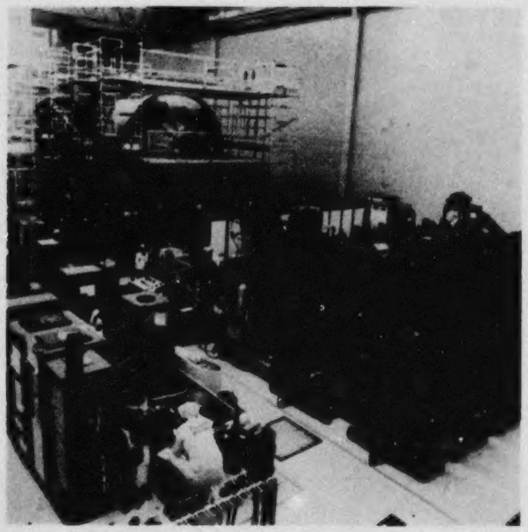
This is a laboratory adapted for work in weightlessness.

Mobility aids such as rails and restraints are needed for comfort and safety in an environment in which the reaction from closing a drawer or stomping a foot can send a crew member gliding through the air. Unattached objects must be fastened to prevent them from floating away and causing injury or damage.

Testing research instruments at laboratory racks inside module, two technicians wear protective clothing to avoid contamination of equipment. Note vertical railings for crew's use in weightlessness.



Spacelab *module in preparation for flight in Operations and Checkout Building, Kennedy Space Center, Florida. In background is engineering model.*



Experiment racks (right foreground) and flight module (center background) are tested in Bremen, West Germany, before shipment to the United States.

Modular Concept Featured

Interior furnishings are modular, so that they can be removed, exchanged, or rearranged in various combinations to serve the needs of specific missions.

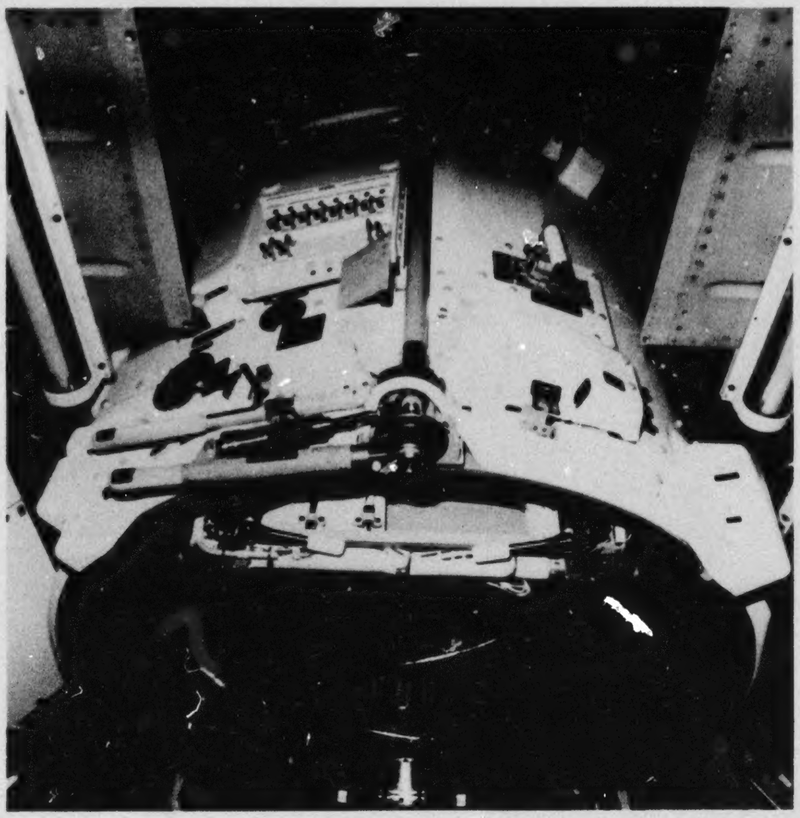
The core and experiment segments each have space for two double racks and one single rack on each wall—a total of eight double and four single racks in the entire long module.

The first double rack on the port side of the core segment—as seen when entering the module from the tunnel—is called the Control Center. It houses the console of the Control and Data Management System (CDMS) which is for all practical purposes the brain and nerve center of *Spacelab*. Its keyboard and video display are the crew's interface with *Spacelab*'s systems. Here the crew obtains readouts informing them of the status of *Spacelab*'s systems and experiments. Here too the crew can command the computers and operate many of the experiments within the module and on the pallet. And here too the crew can adjust the cabin temperature, switch communication modes and do trouble shooting when needed.

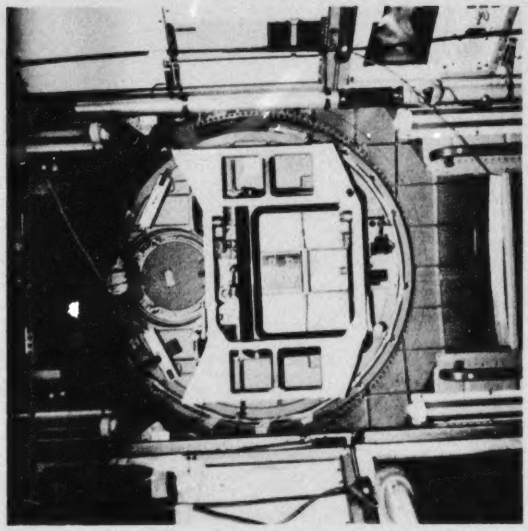
In the first double rack on the right—directly across the aisle from the CDMS controls—are the work bench-desk assembly and also the computers which are controlled from the CDMS.

With these first two double racks taken up by controls and computers, only two double racks and two single racks remain available in the core segment for experiments. In the experiment segment, all racks are available for experiment instruments and equipment.

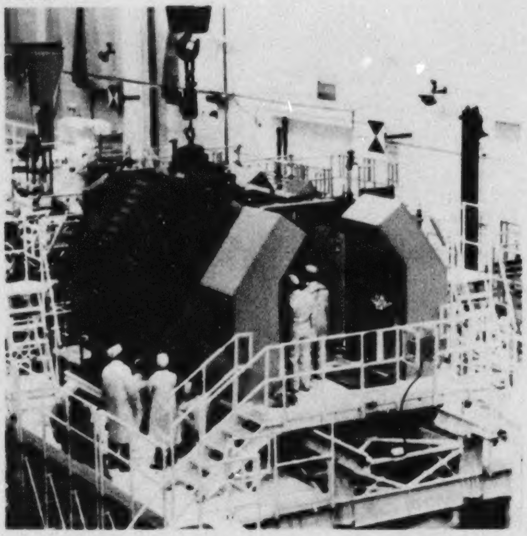
All racks are independently attached to the floor and overhead structure. Racks not needed on a particular mission can be removed. Up to 290 kilograms (645 pounds) of equipment and instruments can be installed in each single rack, up to 580 kilograms (1,290 pounds) in each double rack.



Scientific airlock in the ceiling of the experiment segment allows exposure and retrieval of experiments to outer space without requiring crew members to leave enclosures.



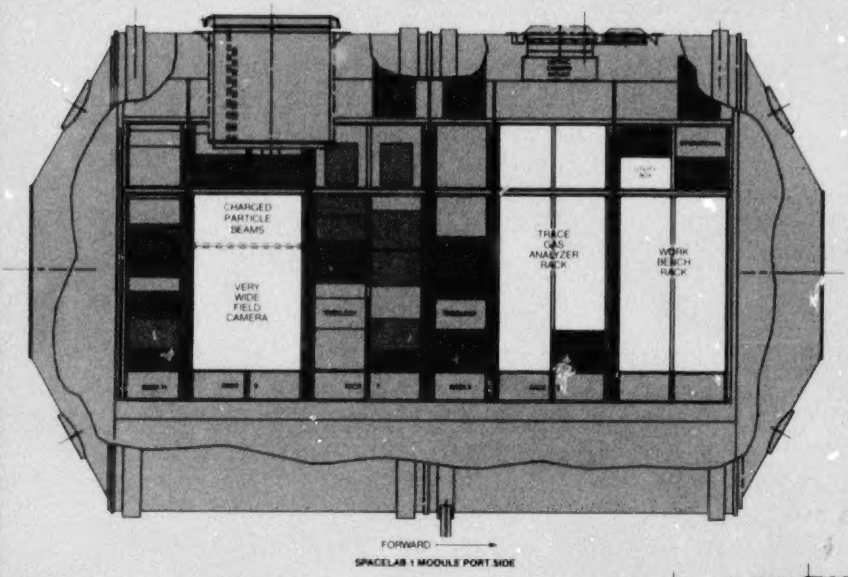
Looking straight up in the core module, as the camera did here, a visitor sees two windows in the ceiling through which crew members can make astronomical and Earth observations.

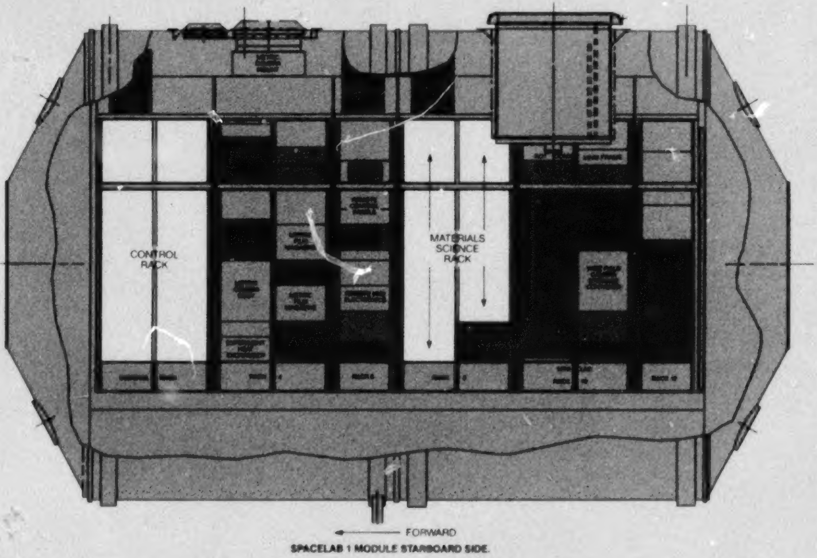


Racks are tested again after arrival at the Kennedy Space Center, Florida.

Instruments and equipment are thoroughly tested before being lifted into and installed in the module and on the pallets. Then, the entire *Spacelab* assembly as needed for a misssion—module, pallets, and the instruments and equipment they carry—are jointly tested to assure their compatibility. Only then, after they have been checked out together, are the fully loaded modules and pallets installed in the cargo bay, thus keeping the Orbiter free for other assignments as long as possible and reducing its turn-around time, the period between its landing and next launch.

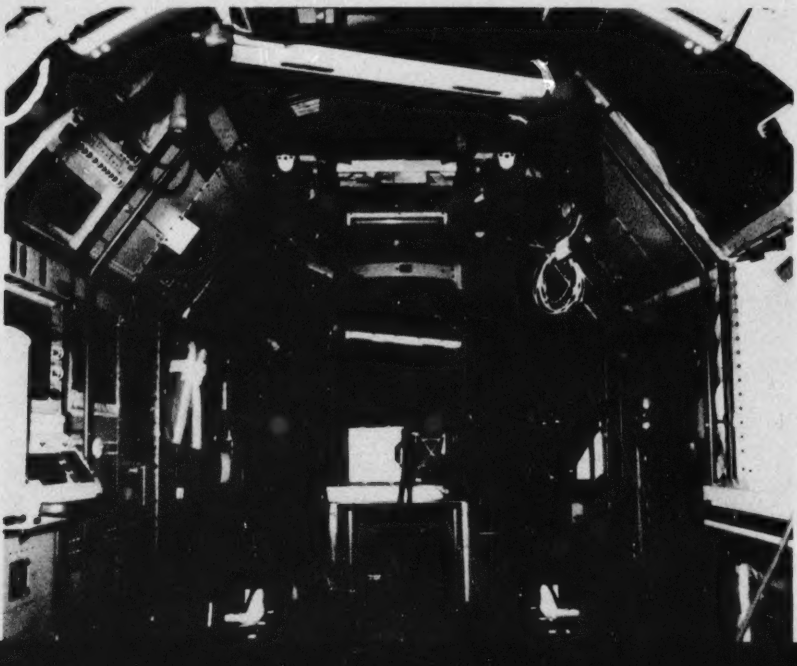
Looking up, the visitor notices that the overhead storage lockers are interrupted twice, first by windows in the ceiling of the


CHARGED PARTICLE BEAMS
VERY WIDE FIELD CAMERA
TRACE GAS ANALYZER RACK
WORK BENCH RACK
FORWARD →
SPACELAB 1 MODULE PORT SIDE


CONTROL RACK
MATERIALS SCIENCE RACK
← FORWARD
SPACELAB 1 MODULE STARBOARD SIDE.

▨ Video/Intercom/Keyboard
▨ Stowage
■ Experiment Power Switching Panel(s) and Access
■ Life Sciences Experiments

Location of Racks.



Two inside views of the habitable module during different phases of preparation.

26

core segment, and second by a large protruding cylinder in the ceiling of the experiment segment on which a tall visitor who is not careful might bump his head.

View from Module Limited

These windows—plus another set at the rear end cone—provide the only outside view for crews in the *Spacelab* modules. Without these windows life inside *Spacelab* would be much like working in a submerged submarine. The windows can be used for celestial and terrestrial observations.

One of the windows in the ceiling assembly is rectangular, measuring 41 by 55 centimeters (16 by 21.5 inches), and is called the high-quality window because it is made of nearly distortion-free, low-reflective glass for observations requiring great precision. Temperature sensors on this window warn crews of the glass's overheating due to excessive sun exposure.

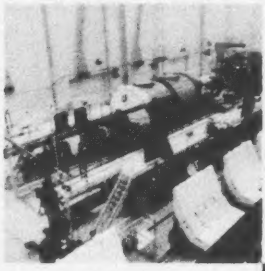
The other window in the assembly is 30 centimeters (12 inches) in diameter and is made of conventional glass containing a heater film coating to prevent fogging from condensation. Through it the crew makes observations and takes photographs requiring less precision.

When the windows are not in use, the crew can protect the entire assembly from micrometeoroid impacts, contamination, and overheating with covers that can be controlled from inside the modules. In flight, crew members can look through the aft end cone's viewport onto the pallets and the instruments mounted there.

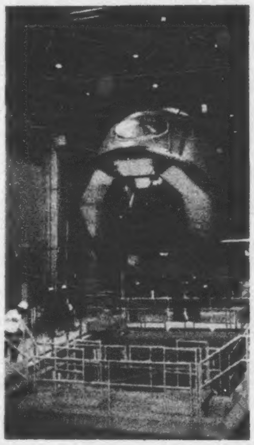
Airlock Chamber Provided

The large cylinder in the ceiling opening in the experiment segment contains an airlock through which the crew can expose instruments and specimens directly to outer space. They can be retrieved later without any crew member having to go outside the module.

The airlock is a cylinder one meter (3.3 feet) long and one meter wide. It is closed by hatches at both ends. Experiments to be exposed to space are attached by the crew to a sliding table that can carry loads of up to 100 kilograms (220 pounds). The airlock's inner hatch has a small viewport for monitoring the exposed experiment. It takes the crew about 10 minutes to drain the air from the airlock before exposure of samples or instruments to the vacuum of space. About 15 minutes are needed to repressurize



Spacelab-1 *module in the checkout facility at the Kennedy Space Center in Florida.*



The engineering model, a replica of the flight unit, is hoisted onto a work stand (top) at the Operations and Checkout Building at the Kennedy Space Center, where engineers and technicians then practice installing equipment (middle). After it was assembled in Bremen, West Germany, the model was tested there (bottom) before being shipped to the United States. Engineering models are used to train personnel and to check the compatibility of auxiliary equipment and the assembly facilities.

the airlock with nitrogen before experiments are retrieved. Several repressurizations are possible on each *Spacelab* flight with the supply of nitrogen aboard the module.

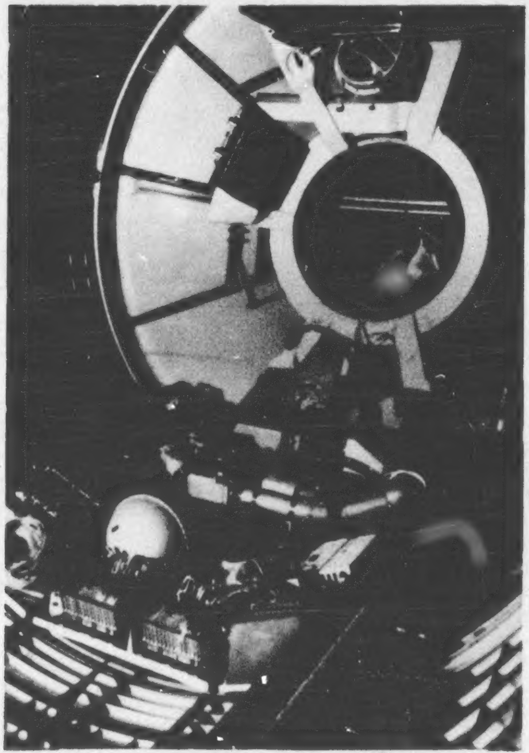
If no airlock is needed, the window assembly from the core segment can be installed in the airlock opening in the experiment segment. Otherwise, the ceiling opening is closed with a cover plate. (The airlock cannot be mounted in the core-segment opening.)

Some important features of *Spacelab* are not readily discernible during a casual visit. Among these less obvious items are the intricate systems that keep the atmosphere clean and the humidity and temperature comfortable for the crew.

Water and air flow through the cooling loops of *Spacelab*'s environmental control system, carrying away heat generated by the bodies of crew members, by the extensive electronic equipment, and by other instruments within the module. Because air does not circulate by itself in weightlessness as it does on the Earth, where warm air rises and colder air sinks, air must be forced under pressure through the equipment racks and other portions of the module.

Spacelab temperatures are kept even with the help of a passive environmental control system, which consists of many layers of foil-covered Mylar with a vacuum between layers. Special paint on the outside helps ward off the Sun's intense heat on one side and the extreme cold of space on the shadow side.

When floor panels are removed in the long module, utility system installations are exposed. Shown are portions of environmental control and electric power distribution systems in module's subfloor.



Temperature and Clean Air Management Provided

In orbit the environmental control loops carry their cooling fluids (water and air inside the module, freon outside the module) to the cargo bay doors, where radiators attached to the doors dissipate the heat into space. During launch and landing, when the doors are closed, the loops unload their heat to the Orbiter's flash evaporators, which boil off ammonia. Water evaporators in the Orbiter augment the system in orbit when the radiators cannot dissipate the total heat load.

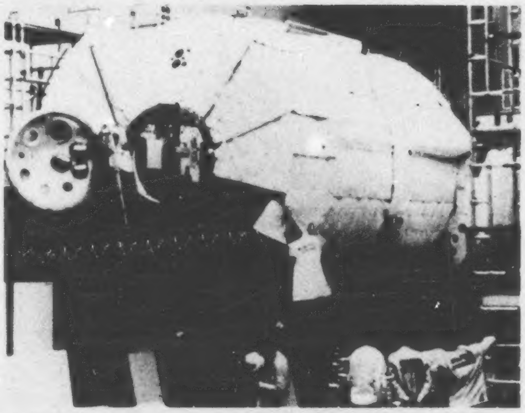
Some of the cooling loops (air ducts and fluid lines) run under the module's floor. Electric power, communications, data transmission, and other utility lines are also located there. Some underfloor storage space for equipment and supplies is available in the experiment segment. Some floor panels are removable in both segments. Thus crew members have limited access to the subfloor space for adjustments and minor repairs, for changing the lithium hydroxide canisters for carbon dioxide removal, and for retrieving items stored in the experiment segment's underfloor bins.

Instruments and equipment requiring extra cooling in the equipment racks inside the module or on pallets can be accommodated with "cold plates" that can be attached to such instruments. Each cold plate is made up of a pair of metal sheets forming a sandwich around tubes through which coolants are cycled.

The environmental control system provides an atmosphere for *Spacelab*'s crew inside the module with the same air pressure and composition as at sea level—14.7 pounds per square inch (10.1 Newtons per square centimeter) with approximately 20 percent oxygen and 80 percent nitrogen—and with room temperatures which the crew can set to their own liking. Oxygen is supplied by the Orbiter. The module carries its own nitrogen supply. The atmosphere is continuously strained through the lithium hydroxide canisters to remove carbon dioxide and occasionally is also cycled through a scrubber to remove contaminants. A vent assembly in the forward end cone expels noxious fumes from experiments directly into space. The assembly's hose can be connected with the experiment chambers in the racks to vent undesirable gases into the vacuum outside.

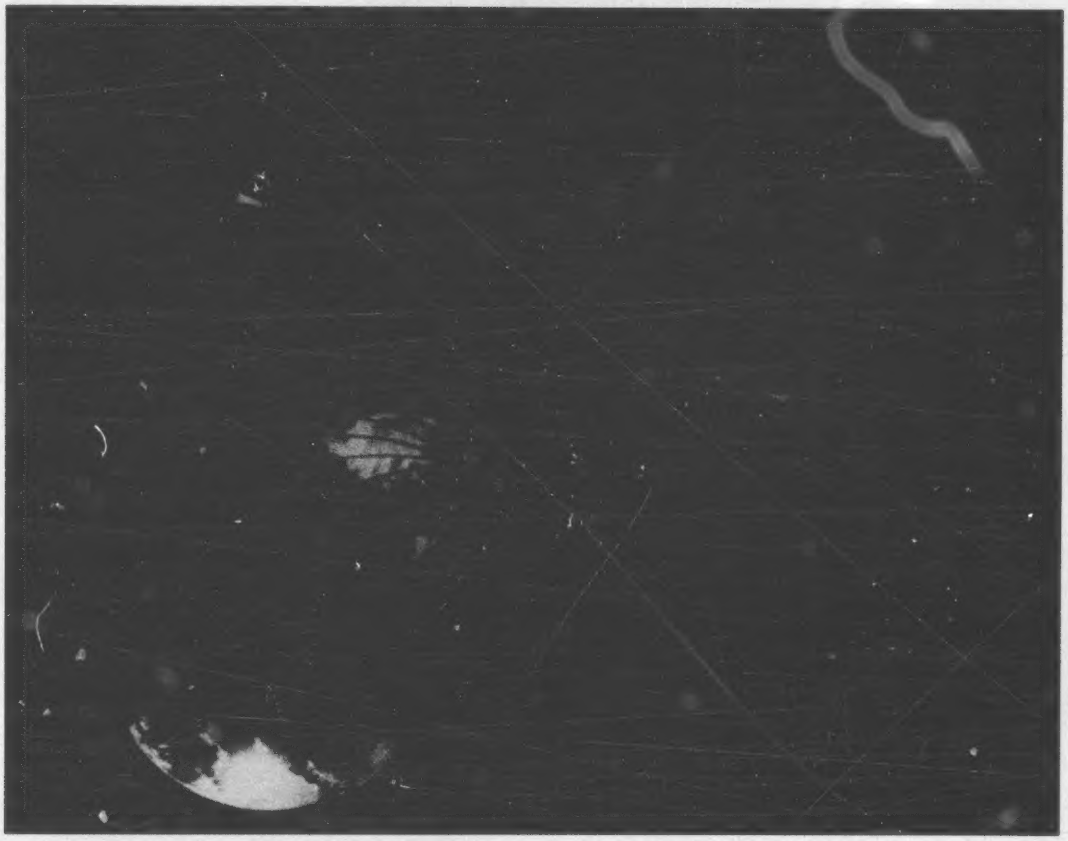
Fuel Cells Furnish Power

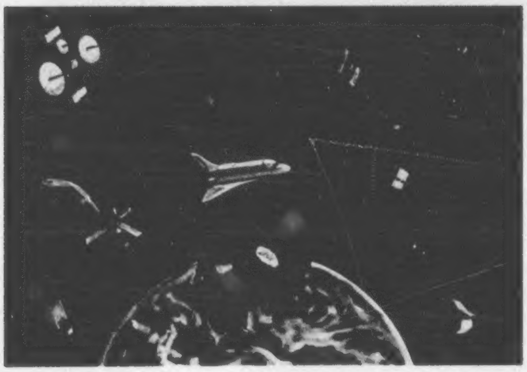
Despite the abundance of sunshine in space, the Orbiter and *Spacelab* do not draw any power from solar cells. None are aboard. Instead, electricity is generated aboard the Orbiter by three fuel cells, one of which is entirely devoted to *Spacelab*. Part of the



Technicians at work on the first Spacelab *flight unit.*

TDRS closeup: Sixteen-foot (4.8-meter) dish antennas project from this TDRS in an artist's concept of a satellite's eye view of the Earth. The paddle-like blue rectangles on long booms are solar panels for powering the satellite.





Two satellites—shown here in the upper left and right corners—comprise NASA's new Tracking and Data Relay Satellite System (TDRSS, pronounced "tea dress") which is to serve Spacelab *and the Orbiter, and numerous applications and science satellites. A third TDRS is to be kept in orbit as a spare. From their Earth-synchronous orbit each TDRS covers about half the globe for relaying communications between orbiting craft and the Earth station at White Sands, New Mexico.*

output of one of the two other fuel cells can also be made available for *Spacelab* if needed.

Fuel cells, which produce electricity from supercold liquefied oxygen and hydrogen by a chemical process, have been successfully used in U.S. manned spacecraft throughout the Apollo flights beginning in the late 1960s. For *Spacelab* operations fuel cells are advantageous because the crew is free to position the Orbiter to suit research needs for astronomical or Earth observations, rather than having to move the Orbiter so that its solar cells face toward the Sun for extended periods to charge its batteries. Fuel-cell-generated electricity from the Orbiter is distributed to *Spacelab* outlets in the module work areas, the equipment racks, and at the pallets to operate the instruments and equipment there. The water that is produced by the fuel cell chemical reaction is used for food preparation, drinking, and evaporative cooling.

Power also goes to *Spacelab*'s three computers—one for supervision of the experiments, another for controlling *Spacelab*'s own housekeeping, and the third as a backup for immediate substitution if either of the others fail.

Museum visitors can stand at a video screen of the Control Center console and watch a payload specialist operate the keyboard while *Spacelab* information appears on the screen. The watcher can get a quick-look analysis on the screen about any *Spacelab* experiment—Is it turned on? What results is it getting? Are there any problems? If so, what are they? Besides acquiring this and other information and making it available to the crew, *Spacelab*'s on-board computers also supervise the multiplexing of the various communication channels into a single data stream, activate the high data-rate and video recorders, and command transmission to Earth.

The computers operate some experiments virtually without human intervention, adjusting deviant instruments back to accuracy within split seconds. They flash a warning if assistance from the crew is required or if an emergency should appear to be imminent. Crew members can enter new instructions into the computers and also override its decisions.

Sixteen Data Channels Available

The computer-associated mass memory can store 132 million bits of data, a quantity which, if it were all stored in words, would be the equivalent of 27 thick books. The computers and the rest of the Control and Data Management System (CDMS) operate separately from the Orbiter data management installations, thus making the CDMS the most independent of all major systems aboard *Spacelab*. However, for transmissions to Earth, the CDMS depends entirely on the Orbiter's communications system. All of *Spacelab*'s communications and data transmissions go through the Orbiter.

One of the key devices for feeding data to the Orbiter's communications system is a very advanced multiplexer which combines 16 channels of instrument information and two voice channels for simultaneous transmission. A crew member in the Orbiter can carry on a conversation with Earth while another crew member in the module talks to the Earth on another voice channel. At the same time, 16 research instruments aboard *Spacelab* can report their condition and their research results to Earth.

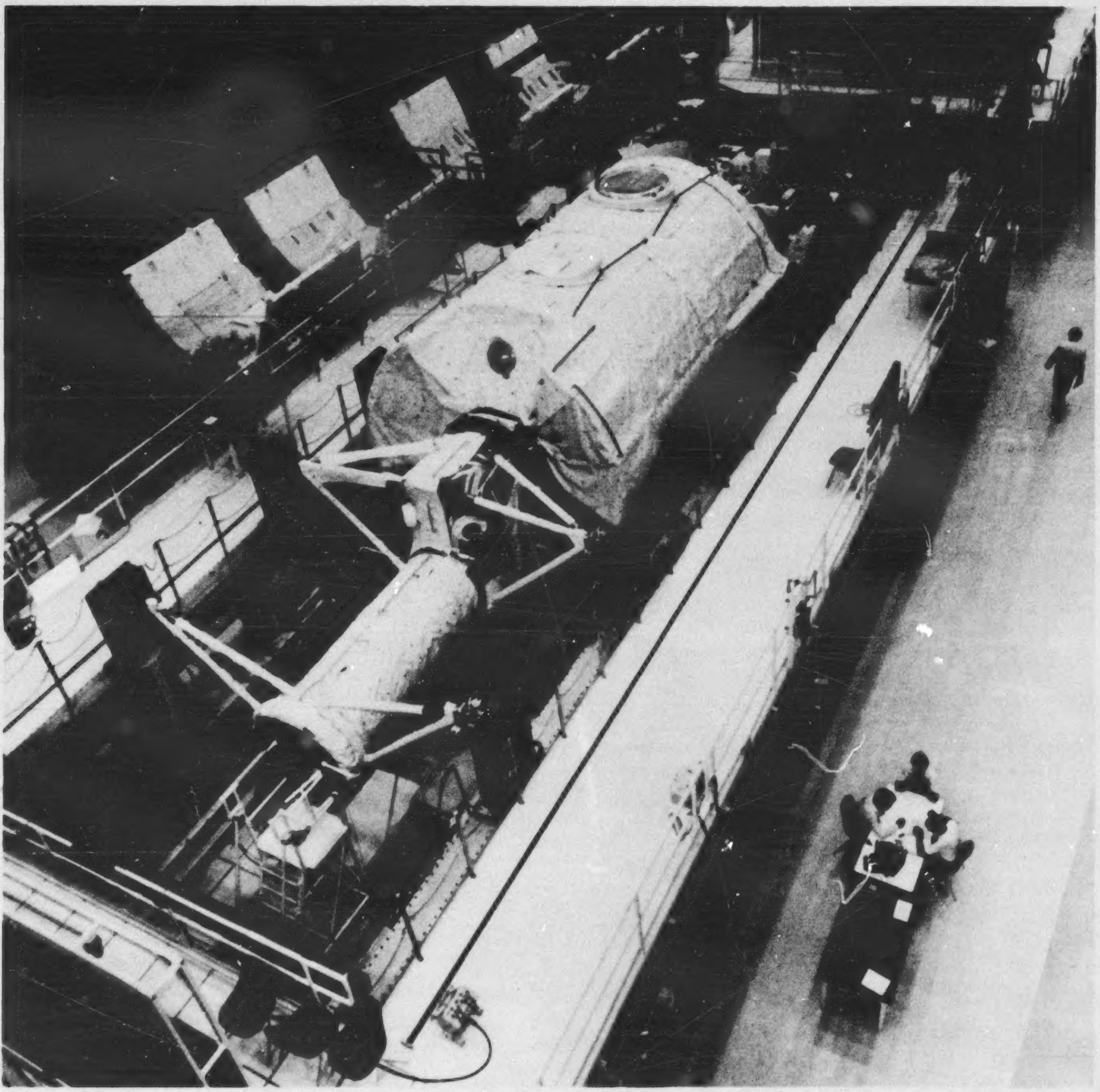
For transmission the Orbiter uses the new Satellite Tracking and Data Relay Satellite System (TDRSS). When completed, that system's transmission of data, voice and television from the Orbiter can be raised to a rate at which, if the transmissions were all in alphabet characters, would equal nearly a million words—or 10 full-length novels—moving from space to Earth each second. With the full TDRSS in operation, contact can be maintained with Mission Control at least 30 to 80 percent of the time.

Tunnel Provides Module Access

At the front end of the module in the center of the end cone—between the double racks holding the Control Center and the workbench-desk—is the entrance to the tunnel that leads to the Orbiter's mid deck. The tunnel, the only major in-orbit component of *Spacelab* supplied by NASA, comes in two lengths to permit positioning the modules closer or farther away from the Orbiter's flight and mid decks. This flexibility in the module's placement is necessary to maintain the Orbiter's desired center of gravity under varied loading conditions. Since *Spacelab*'s length varies depending on the configuration used—whether a long or short module or one or more pallets are carried—loading conditions differ for each flight.

The tunnel is wide enough so that crew members after some practice can carry packages of up to 56 by 56 by 127 centimeters (22 by 22 by 50 inches) through it from the mid deck to the modules. This makes it possible to store some *Spacelab* supplies in the Orbiter mid deck.

Tunnel is being fitted to long module during tests at the Kennedy Space Center in Florida.

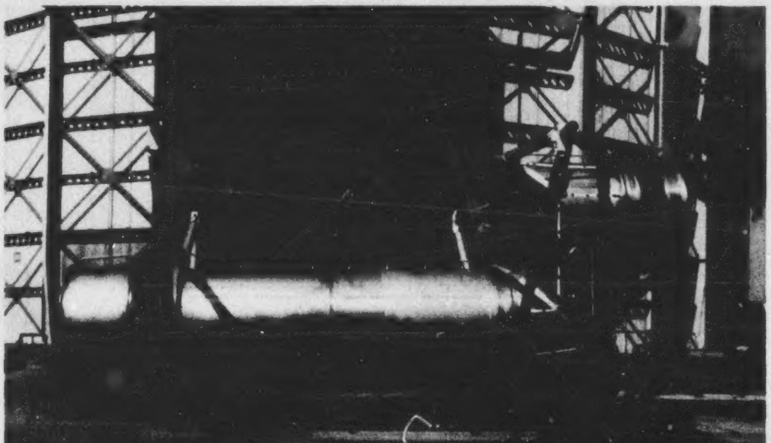


Through a hatch near the tunnel's junction with the Orbiter's mid deck, space-suited crew members can pass outside on extravehicular activities (EVA), also known as space walks. Some flights call for such EVAs to carry out experiments in the vacuum of space. Unscheduled EVAs can become necessary, for maintenance and repair work on pallet-mounted instruments, or on the cargo bay doors' closing mechanisms, or on other Orbiter or *Spacelab* components.

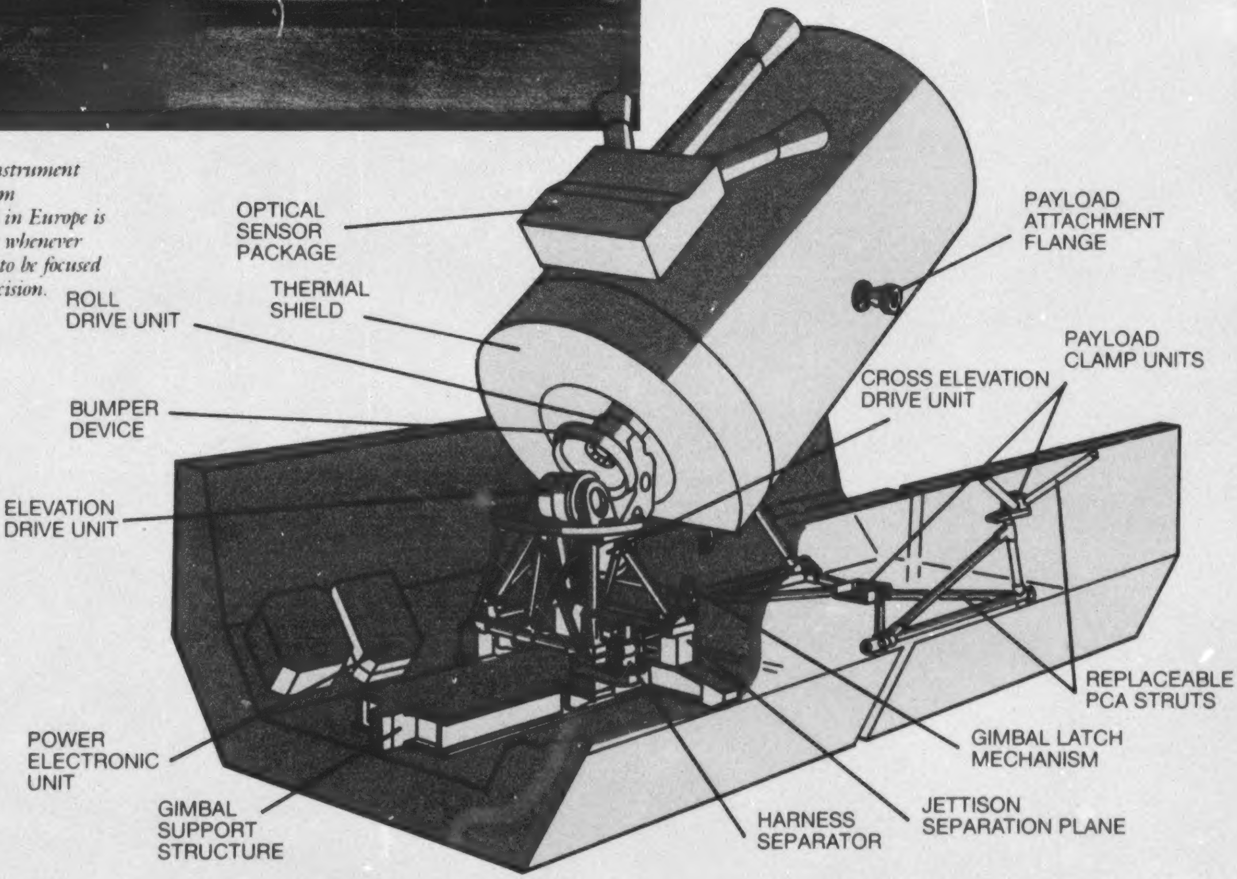
In pallet-only missions—when no module is on board—a vertical drum, 2.4 meters high and weighing 630 kilograms (1,400 pounds) is attached to the forward pallet to provide services otherwise offered by the modules. The drum is called an "igloo" and maintains the same interior temperature and atmosphere as a module. The igloo contains necessary power-distribution, command and data equipment and other utility resources to serve pallet instruments. In the pallet-only configuration, the research instruments and utility installations are controlled from the Orbiter's aft flight deck or from the ground.

Special services for experiments which require them can be made available by the Orbiter-*Spacelab* system. For example, telescopes often need to be kept pointed for relatively long periods with extraordinary precision at very faint, extremely distant celestial targets. The Orbiter's maneuvering ability using the thrusters of the reaction control system rarely exceeds an accuracy better than one-half a degree and often comes within only two degrees of accuracy—roughly equal to holding an instrument on the Earth pointed at the full disk of the Moon.

Z-shaped tunnel arrives for installation in Orbiter's cargo bay.



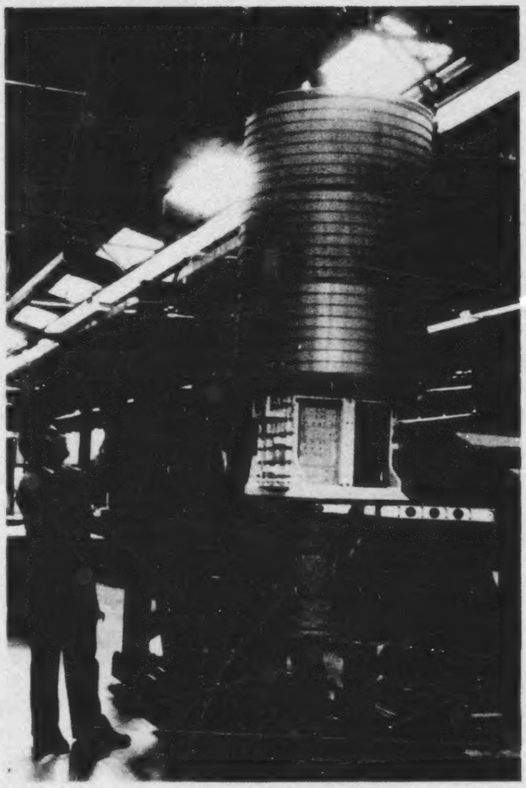
The one-ton Instrument Pointing System manufactured in Europe is used on pallets whenever telescopes need to be focused with great precision.


OPTICAL SENSOR PACKAGE
PAYLOAD ATTACHMENT FLANGE
THERMAL SHIELD
ROLL DRIVE UNIT
PAYLOAD CLAMP UNITS
CROSS ELEVATION DRIVE UNIT
BUMPER DEVICE
ELEVATION DRIVE UNIT
REPLACEABLE PCA STRUTS
GIMBAL LATCH MECHANISM
POWER ELECTRONIC UNIT
GIMBAL SUPPORT STRUCTURE
HARNESS SEPARATOR
JETTISON SEPARATION PLANE

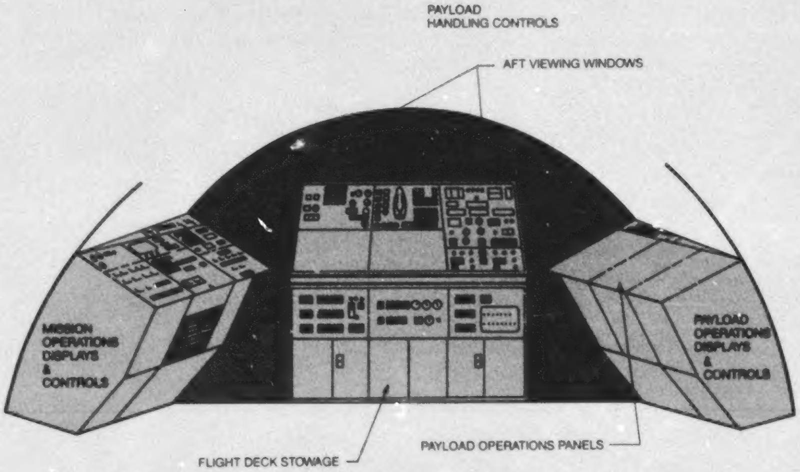
Pointing Device Provided

For very precise aiming, an Instrument Pointing System (IPS) is being developed by the European Space Agency. Weighing about a ton, the IPS is installed on a pallet whenever it is needed on a mission, to focus instruments on their targets with an accuracy within 1.2 arc-seconds. This is equal to keeping an instrument on the Capitol steps in Washington, D.C., aimed at a dime-size coin at the Lincoln Memorial 3.6 kilometers (2¼ miles) away. The IPS keeps instruments on target even when crew movements or equipment operations cause the Orbiter to vibrate. The IPS can be programmed to work automatically or it can be controlled from the Orbiter's flight deck. As a safety precaution in the event that the IPS cannot be retracted and restowed after use, thus preventing the cargo bay doors from closing for reentry, the entire IPS can be jettisoned into space, as can the airlock outer hatch if it should fail to retract.

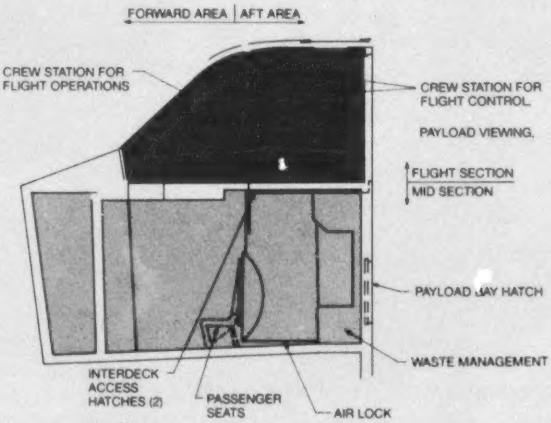
To avoid flying over land areas during early ascent, flights launched from Kennedy Space Center in Florida are not sent into orbits with an inclination steeper than 57 degrees. However, this permits orbital paths that bring *Spacelab* far enough north to cover all of the United States, the southern half of Canada, all of Central Europe and all except the most northerly parts of Asia—and far enough south to pass over all the major land masses in the Southern Hemisphere except Antarctica. When Shuttle launch facilities are completed at the Vandenberg Air Force Base in California, the Shuttle can be launched into orbital inclinations permitting *Spacelab* to overfly nearly the entire earth. Altitudes



"Igloo," being readied for use, holds Spacelab *computers and other vital equipment in pallet-only flights.*


PAYLOAD HANDLING CONTROLS
AFT VIEWING WINDOWS
MISSION OPERATIONS DISPLAYS & CONTROLS
PAYLOAD OPERATIONS DISPLAYS & CONTROLS
PAYLOAD OPERATIONS PANELS
FLIGHT DECK STOWAGE

Orbiter's aft flight deck.


FORWARD AREA | AFT AREA
CREW STATION FOR FLIGHT OPERATIONS
CREW STATION FOR FLIGHT CONTROL
PAYLOAD VIEWING.
FLIGHT SECTION
MID SECTION
PAYLOAD BAY HATCH
WASTE MANAGEMENT
INTERDECK ACCESS HATCHES (2)
PASSENGER SEATS
AIR LOCK

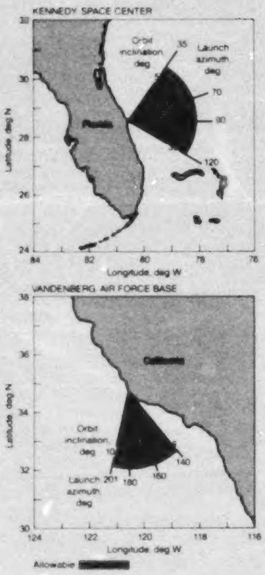
Orbiter's cabin.

obtainable for Orbiter-*Spacelab* flights depend on the loads carried and on desired inclinations. Altitudes may range from about 160 to 400 kilometers (about 100 to 250 miles).

Despite its variety of components and systems and the complexity of its tasks, *Spacelab* required no major technological breakthroughs. Its innovative design and construction are based on well-established engineering principles and proved techniques. Checks and tests to which *Spacelab* was subjected are conservative procedures followed painstakingly by ESA and NASA to assure the safety of all systems intended for space flights with human crews.

A tour through *Spacelab* is much more than a walk past a hallmark collection of engineering achievements. As with many other multifaceted engineering entities, with *Spacelab* the whole adds up to more than the sum of its parts.

Spacelab is a tool for doing old things in new ways, and for trying out new things that could not previously be done as well or at all. That is the essence of *Spacelab* as it follows a proven route to innovation and progress.


KENNEDY SPACE CENTER
Orbit inclination deg
35
Launch azimuth deg
70
90
120
Latitude deg N
30
28
26
24
84
82
80
78
76
Longitude, deg W
VANDENBERG AIR FORCE BASE
38
36
34
32
30
Latitude deg N
Orbit inclination deg
140
160
180
201
Launch azimuth deg
124
122
120
118
116
Longitude, deg W
Allowable

Orbital inclinations and launch azimuths.

Interior view of long module (engineering model), outfitted with experiment racks and other systems, during test at Spacelab's *prime contractor,* ERNO, *in Bremen, West Germany.*

“Spacelab *circles our Earth in less than two hours. From its altitude national boundaries are unrecognizable. Its crew sees the Earth as one entirety. It is a small planet in the void of the Universe. One planet. One common home. It is a home which, with the help of space technology, has become surveyable in a single view, a home which we must be careful not to destroy. In fostering this awareness lies perhaps the truly epochal meaning of today's space technology.*

“I wish this new space laboratory and its mother ship, the Shuttle, and their combined crews good flights in space and many happy returns to solid Earth.”

Dr. Wolfgang Finke, Chief, Space and Aviation Research, West German Ministry for Research and Technology, December 4, 1981, at the presentation to NASA of the first *Spacelab* flight unit in Bremen, West Germany.

CHAPTER 3

Meet the Crew

Meet a new breed of space travelers! They are called payload specialists and they are the first *non*-career astronauts in space.

Typically they are scientists whose only reason for going on a space flight is to carry out some specific research in their own field of expertise.

Though they are considered to be members of the crew, they are *not* trained for and do *not* need to know how to operate the Shuttle, nor do they need to pass the stringent physical examinations required for career astronauts.

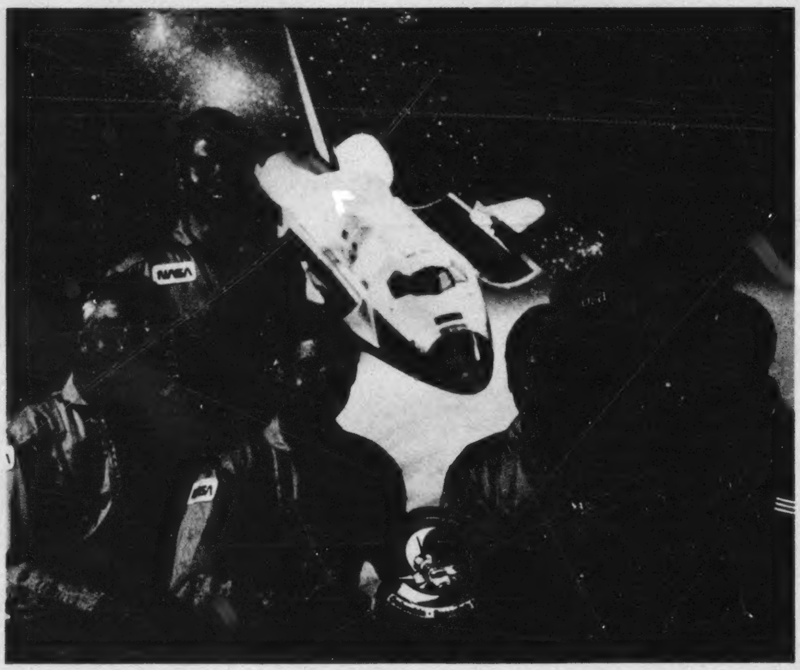
Payload specialists are the first passengers on manned space flights. Like riders on a bus or airliner, they leave the operation of the vehicle to professional drivers. While these payload specialists concern themselves with the conduct of their in-space scientific experiments, the navigation and other operational tasks for the Orbiter and *Spacelab* are handled by the career astronauts in the crew.

Payload specialists are new to NASA. They are making their first in-flight appearance aboard the first *Spacelab* flight—SL-1. That flight has two payload specialists in its six-member crew. The other four crew members are the commander, the pilot, and two mission specialists.

Up to three payload specialists are expected to be on board future *Spacelab* flights, along with one or two mission specialists plus the commander and the pilot, for a total crew of six or seven members.

Mission specialists, also a new concept in U.S. space flights, made their first in-space appearance on the fifth Shuttle flight—STS-5—in November 1982. Since then two or three mission specialists have flown aboard each Shuttle mission.

Thus, personnel specialization is entering space in a big way. Though scientists and physicians have flown on U.S. spacecraft before and some astronauts have been trained for specialized tasks, in all of the first 36 U.S. manned space flights in the 22 years through November 1982 all crew members had been essentially cross-trained. Each crew member was fully prepared to take over the tasks of any of the others and, if need be, the operation of the vehicle. Scientists who were members of these crews all had joined the astronaut corps, had become career astronauts, and had undergone the same strenuous training as their test pilot colleagues for several years before making their first space flights.



Crew for first Spacelab *flight.*

Assignments for Crew

In *Spacelab* flights, crew specialization calls for these assignments of responsibilities:

The commander and the pilot control the Orbiter and assure its operation according to the flight plan. They monitor its performance and steer and position it as necessary during launch, in orbit, and during reentry. The commander and pilot are career astronauts with several years of astronaut training and earlier experience as aviators and test pilots. The commander is responsible for the safe conduct of the mission and for the safe return of crew and craft.

Mission specialists are both professional scientists and career astronauts. Thus they are a link or bridge between the other crew members. Mission specialists have professional academic training as well as practical experience in at least one field of science or engineering. They have joined the astronaut corps.

They understand the Orbiter's as well as *Spacelab*'s systems. They monitor, adjust, and service these systems. They include environmental control, communications, power generation and distribution, data processing and transmission, and even the mechanism for opening and closing the cargo bay doors. As their time permits, mission specialists work side by side with payload specialists in carrying out research. If work outside the Orbiter is required—for repairs or for the conduct of a scientific experiment—mission specialists are trained and equipped for space walks, formally known as extravehicular activities (EVAs). Thus it can be said that mission specialists combine the functions of resident maintenance engineers, in-space counterparts of flight engineers in aircraft, and fully qualified scientists.

Payload specialists are professional scientists or engineers whose only assignment on a space flight is to carry out scientific and technological experiments. Their specific training for a space flight is usually limited to a short period of learning how to live and work—how to move around, prepare food, eat, and use faucets and sanitary facilities—in weightlessness. They are kept free from routine operational duties. They can thus apply their attention to monitoring scientific research instruments, to observations, and to using their scientific experience and judgment for the accommodation and adjustment of instruments to unexpected conditions.

After completion of a flight, payload specialists return to their careers at research laboratories while the other crew members continue their training and preparations for another flight.

Crew Concepts Changing

The introduction of mission specialists and payload specialists is fundamentally altering both the composition and the public's image of U.S. space flight crews. The public's perception is changing as the Shuttle becomes a routine, operational space transportation system and *Spacelab* also becomes operational. The 22-year male monopoly in U.S. manned space flight is now history. Eight women have completed several years of astronaut training at the Johnson Space Center in Houston, Texas, and are available for assignment to space flight crews. One of these, Dr. Sally K. Ride, a former Stanford University physicist, became the first woman aboard an orbiting U.S. spacecraft as a mission specialist on the seventh Shuttle flight (STS-7) in June 1983.

What a typical crew is like—and the diversity of backgrounds represented within it—is best illustrated by a closeup look at the six people assigned to the first Spacelab *mission, designated SL-1. Because it also is the ninth flight for the Shuttle—the Space Transportation System (STS)—the flight is also designated as STS-9.*

In terms of the combined professional experience of its crew (not to mention the quality of its research instruments) STS-9/SL-1 could well become the envy of many research laboratories on Earth. In the six-man crew are scientists, engineers, and veteran pilots. Each of the six has a background in a different specialty.

The crew for *Spacelab* 1:

Commander:	John W. Young, veteran astronaut
Pilot:	Brewster H. Shaw, Jr., veteran jet pilot
Mission Specialist:	Dr. Owen K. Garriott, electrical engineer
Mission Specialist:	Dr. Robert A.R. Parker, astronomer
Payload Specialist:	Dr. Byron K. Lichtenberg, MIT biomedical engineer
Payload Specialist:	Dr. Ulf Merbold, West German physicist

Spacelab-1 *crew: Commander John W. Young; Pilot Brewster H. Shaw, Jr.; Mission Specialist Dr. Owen K. Garriott; Mission Specialist Dr. Robert A.R. Parker; Payload Specialist Dr. Byron K. Lichtenberg; Payload Specialist Dr. Ulf Merbold.*

©National Geographic Society Painting by Roy Andersen

The first four—all career astronauts—have spent a combined total of 60 years in training as full-time members of the astronaut corps. Two of them—Young and Garriott—have lived for a combined total of 12 weeks in space on earlier flights. Four of the six have earned Ph.D. degrees, each in a different field. All are married and all have children: Garriott has four, Shaw three, and the others two each, for a combined total of fifteen children, ranging in age from 7 to 28 years.

The Commander

John W. Young at age 53 easily qualifies for the title of the world's most experienced space traveler. He has been a full-time astronaut for 21 years. He has flown in a record five space flights—in three of these as commander—in three generations of spacecraft, spending a total of 27 days in space. That total includes three days of living on the surface of the Moon.

SL-1 is Young's sixth flight into space, his fourth as commander, and the mission will make him the first person to fly a second time on three kinds of spacecraft. He was the commander of the Shuttle's first orbital flight, STS-1, April 12 to 14, 1981.

Born in San Francisco on September 24, 1930, Young grew up in Orlando, Florida, where his parents still live. He earned a bachelor of science degree with highest honors in aeronautical engineering from Georgia Institute of Technology in 1952. He joined the U.S. Navy and, as a Navy test pilot, set world time-to-climb records to 3,000 and 25,000-meter altitudes in 1962, just before he was selected as an astronaut in September of that same year.

He was on two separate orbital flights in the two-man Gemini spacecraft (Gemini 3 in 1965 and Gemini 10 as commander in 1966) and on two separate flights in the three-man Apollo—Apollo 10, which orbited the Moon 31 times in May 1969, and Apollo 16, which achieved landing on the Moon in April 1972. As commander of that last flight, Young and a colleague collected 90 kilograms (200 pounds) of Moon rocks during 20 hours of scientific explorations in which they walked and drove in the lunar roving vehicle for 43 kilometers (27 miles) through the rugged lunar highlands. Since January 1975, Young has been the chief of the Astronaut Office which schedules and coordinates all astronaut activities. This makes him director of all of NASA's six dozen astronauts at the Lyndon B. Johnson Space Center in Texas.

The Pilot

Brewster H. Shaw, Jr., 38, the SL-1 pilot who assists Young and alternates with him during shift changes in the Shuttle cockpit, is a U.S. Air Force test pilot and former test pilot instructor with more than 3,000 hours of flying time in more than 30 types of aircraft. He has been an astronaut since January 1978. SL-1 is his first space flight. A native of Michigan, he earned bachelor and master of science degrees in engineering mechanics from the University of Wisconsin at Madison in 1968 and 1969 before joining the Air Force.

Mission Specialist

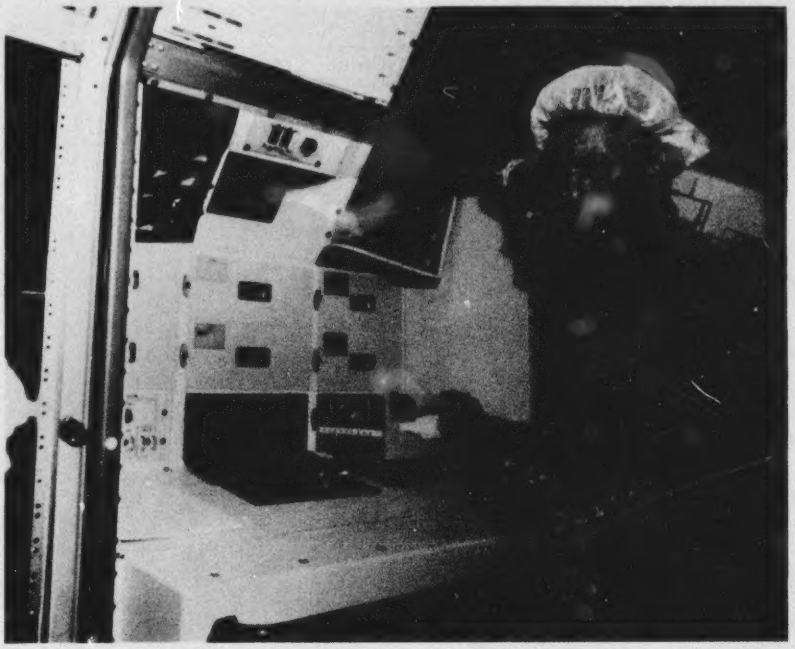
Dr. Owen K. Garriott, 52, one of the two SL-1 mission specialists, is one of NASA's most experienced scientist-astronauts. Though stationed at the Johnson Space Center in Houston, Texas, as a full-time member of the astronaut corps for more than 18 years, he still retains his consulting professorship at Stanford University in California, where he taught electronics, electromagnetic theory, and ionospheric physics from 1961 until he became an astronaut in 1965. He has done extensive research in ionospheric physics—studies of the upper atmosphere—and has published a book and 30 scientific papers in this field.

Garriott lived in orbit continuously for 59½ days from July 28 to September 25, 1973, as a member of the second three-man crew that occupied *Skylab*, the 100-ton U.S. orbital research space station. On that mission Garriott spent a total of 13 hours and 43 minutes working outside *Skylab* on three separate space walks.

A native of Enid, Oklahoma, where his parents still live, he earned a bachelor of science degree in electrical engineering from the University of Oklahoma in 1953. He received a master of science degree in 1957 and a doctorate in electrical engineering in 1960, both from Stanford University. He served as an electronics officer in the U.S. Navy from 1953 to 1956, and has logged more than 3,900 hours piloting aircraft. He interrupted his astronaut activities, serving briefly as director of applications and assistant director for space science at the Johnson Space Center, before going into mission specialist training.

Mission Specialist

Dr. Robert A.R. Parker, 46, Garriott's colleague as SL-1 mission specialist, has also been a member of a college faculty. He was an associate professor of astronomy at the University of Wisconsin until his selection as an astronaut in 1967. Though he has been in training as an astronaut for 16 years, SL-1 is his first space flight. He grew up in Shrewsbury, Massachusetts, where his parents still live. He earned a bachelor's degree in astronomy and physics at Amherst College in 1958 and a doctorate in astronomy from the California Institute of Technology in 1962.



Veteran Scientist-Astronaut Dr. Owen K. Garriott is a mission specialist on the first Spacelab *flight.*

Payload Specialist

Dr. Byron K. Lichtenberg, 35, a researcher in biomedical engineering at the Massachusetts Institute of Technology (MIT), is the youngest member of the SL-1 crew. He is the first American to fly in an orbiting U.S. spacecraft who is not and never has been a

member of the astronaut corps. His name also goes into history as the first American scientist to carry out an experiment in space that he helped design and that he will help analyze and interpret as a member of a research team. In the past scientists instructed astronauts on how they wanted their experiments carried out so that the astronauts could do it for them.

Lichtenberg is a member of an MIT biomedical engineering research group tracing the causes of—and seeking ways to prevent—motion sickness. At the time of his selection for the SL-1 flight crew, Lichtenberg was participating with other members of that research group in the design of an experiment for use in SL-1 for learning more about the workings of the gravity-sensitive mechanism in the inner ear called the vestibular organ. This is the organ that helps us sense change of speed and direction of body movement even when our eyes are closed. When the vestibular mechanism is disturbed by disease or unusual movements—such as in a boat or airplane—some people become seasick or airsick. In the absence of gravity several astronauts have complained about another variety of motion sickness known as space sickness. Lichtenberg is scheduled to carry out several experiments on himself and his fellow crew members in the absence of gravity in orbit.

Lichtenberg, who was born in Stroudsburg, Pennsylvania, in 1948, earned his bachelor of science degree in electrical engineering from Brown University in 1969, then served in the U.S. Air Force for four years until 1973, winning two Distinguished Flying Crosses during his tour of duty in Vietnam. He received his master's degree in mechanical engineering in 1975 and his doctor of science degree in biomedical engineering in 1979, both from MIT. He is the first American selected for travel on a U.S. spacecraft by a committee of the scientists whose experiments are aboard the flight (as explained later).

Payload Specialist Dr. Byron K. Lichtenberg works on experiment racks inside long module during training at Marshall Space Flight Center, Huntsville, Alabama.

Payload Specialist Dr. Byron K. Lichtenberg practices a technological experiment in replica of Spacelab *module.*

The original five payload specialist candidates, selected from several thousand applicants, gather in front of a Spacelab *table model in February 1982 as they begin intensive training. Since then, Dr. Byron K. Lichtenberg (extreme right) of the United States and Dr. Ulf Merbold (second from left) of West Germany have been selected for the flight crew for the first* Spacelab *mission. Dr. Michael L. Lampton of the United States (center) and Dr. Wubbo Ockels (left) of the Netherlands are the alternates. Dr. Claude Nicollier (second from right) of Switzerland is in training as a mission specialist at the Johnson Space Center in Houston.*

Payload Specialist

Dr. Ulf Merbold, 42, a physicist specializing in metals research, is the first non-American to be launched into space aboard an American spacecraft.* A citizen of West Germany, he is a former staff member of the Max Planck Institute in Stuttgart, and an employee of the European Space Agency (ESA) while he is working on the SL-1 mission. He was selected by ESA as the SL-1 payload specialist representing European scientists.

Born in Greiz, Germany, in 1941, he was graduated in 1968 from Stuttgart University and received a doctorate in science there in 1978. He joined the Max Planck Institute for Metals Research on a scholarship in 1968 and later as a staff member.

The commander, the pilot, and the two mission specialists were selected from about 70 active members of the U.S. astronaut corps at the Johnson Space Center in Houston in the traditional way by NASA officials, who customarily assign astronauts to specific missions.

But selection of the two SL-1 flight payload specialists—Lichtenberg and Merbold—came about through an unprecedented procedure.

Scientists Choose Candidates

In May 1978 a committee composed of the U.S. members of the SL-1 Investigators

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**Only once before have non-Americans been inside an orbiting U.S. spacecraft, but they were neither launched in it nor did they return in it to Earth. That was on July 17 and 18, 1975, during the Apollo Soyuz flight, when a U.S. Apollo with three U.S. astronauts linked in orbit with a Soviet Soyuz carrying two cosmonauts. The American and Soviet crews visited each other by passing through a tunnel connecting the joined craft. On that flight, Soviet cosmonauts Aleksey A. Leonov and Valeriy N. Kubasov each spent several hours inside the orbiting Apollo before they returned to their own craft and completed their flight in the Soyuz.*

Working Group (IWG) met at the Marshall Space Flight Center in Huntsville, Alabama. It nominated two American payload specialist candidates: Lichtenberg and Dr. Michael L. Lampton of the University of California, Berkeley, whose research had encompassed space physics, X-ray and ultraviolet astronomy, and optical and electronics engineering.

The ESA selection process began in December 1977 when ESA in consultation with the European scientists who were then building SL-1 experiments announced the selection of three payload specialist candidates from more than 2,000 European applicants: Merbold; Dr. Wubbo Ockels, a nuclear physicist from the University of Groningen, the Netherlands; and Dr. Claude Nicollier, a Swiss astronomer.

The five began preparing for the mission by acquainting themselves with the experiments and with the *Spacelab* components and systems, all of which were under construction.

While *Spacelab* was being built in Europe, the Shuttle, being built in the United States, was encountering problems with the heat-protective tiles that cover its underside and with the performance of its revolutionary new rocket engines. These problems delayed the Shuttle's readiness for flight, giving the payload specialist candidates unexpected extra time for training. They also were able to return occasionally to their jobs at their laboratories for several weeks at a time between their payload specialist preparations, until their intensive full-time training began in January 1982.

Payload Specialist Dr. Ulf Merbold trains himself for work with research instruments for first Spacelab *flight.*

Meanwhile, Nicollier was assigned by ESA to mission specialist training at the Johnson Space Center. Thus he was no longer a contender for the payload specialist assignments, leaving the European competition to Merbold and Ockels.

The four (Lichtenberg, Lampton, Merbold, and Ockels), together with the two mission specialists, traveled and met most of the more than 70 SL-1 principal investigators in the United States, Europe, and Japan. They learned from them the details of these experiments, how to operate and adjust them, and how to make corrections if necessary for almost every conceivable contingency.

Then the four payload specialists, together with the mission specialists, began training in the *Spacelab* Payload Crew Training Complex at the Marshall Space Flight Center. The model's interior closely resembles the interior of the SL-1 module. The candidates became acquainted with the experiment arrangements in the racks and the other module facilities. They practiced conducting experiments simultaneously and in prescribed sequences, simulating in-flight routines. Computer facilities simulated experiment results, and candidates practiced monitoring, interpreting, and responding to them.

Variety of Training Provided

In nonstop training sessions that kept the candidates inside the module more than 12 hours each day, they became accustomed to the SL-1 work routine, which calls for two 12-hour shifts so as to keep SL-1 in operation on a continuous 24-hour-a-day basis during the flight. On the mission either the commander or pilot is on duty on the flight deck at all times, and one mission specialist and one payload specialist are on duty in either the module or on the flight deck, while the other three crew members sleep or relax until they take their turns on a 12-hour shift.

The payload crew (both mission and payload specialists) were taken on flights in KC-135 jet aircraft in which weightlessness is simulated for up to 30 seconds at a time by operating the craft in parabolic curves to create a situation resembling the sensation one feels for a few seconds in a very fast-descending elevator. During such brief periods of weightlessness the candidates practiced eating, drinking, and using various utensils as they would later in the Orbiter and the *Spacelab* module. The payload and mission specialists trained in the Orbiter model at the Johnson Space Center to acquaint themselves with the Orbiter's flight and mid decks and to practice living in them.

On September 30 and October 1, 1982, the IWG held a historic meeting at the Marshall Center to review all science aspects of the SL-1 flight. By the end of that meeting the group had also made the crucial final selection of their own SL-1 in-flight representative. With the approval of NASA they had selected Lichtenberg for the prime crew and Lampton as the alternate for the SL-1 payload specialists positions. The alternate provides scientific support to the mission from the Payload Operations Control Center while the flight is in progress. Meanwhile Merbold was chosen by ESA for the prime and Ockels as the alternate.

Thus the researchers who designed and built the experiments, and who are to analyze the results, helped select from their peers the two in-flight specialists who are to be in charge of carrying out research in orbit.

Crew Can Total Seven

The SL-1 six-man crew will be exceeded soon. Crews of seven are expected to be assigned to some *Spacelab* flights.

On each of the two Shuttle flights preceding *Spacelab*-1—STS-7 and STS-8—a physician was added to the crews. As flight crews grow in numbers, the inclusion of a physician becomes logical to tend to the health of the crew, provide care in the event of illness or accident, carry out studies on the impact of prolonged weightlessness on the human system, and, particularly, to extend the continuing investigations of motion sickness to which SL-1 is expected to make major contributions.

Sending Ph.D.'s and physicians into space ceased long ago to be a novelty. Except for the very earliest manned space flights, such assignments have been common in the U.S. space program. The first American Ph.D. in space was Edwin E. ("Buzz") Aldrin, Jr., then 36, who made his first space flight in November 1966 aboard the Gemini 12. It was the last mission of the 10-flight series with the two-man Gemini spacecraft, and Aldrin, who had written his doctoral dissertation on orbital mechanics, made landmark contributions toward achieving that flight's objective of going into formation flight—"rendezvous"—with an unmanned orbiting Agena craft and then linking up—"docking"—with it. Aldrin was the second person in history—and the first Ph.D.—to walk on the Moon. He had earned his doctorate in astronautics at the Massachusetts Institute of Technology in 1963 and had been in the U.S. Air Force where he became a colonel.

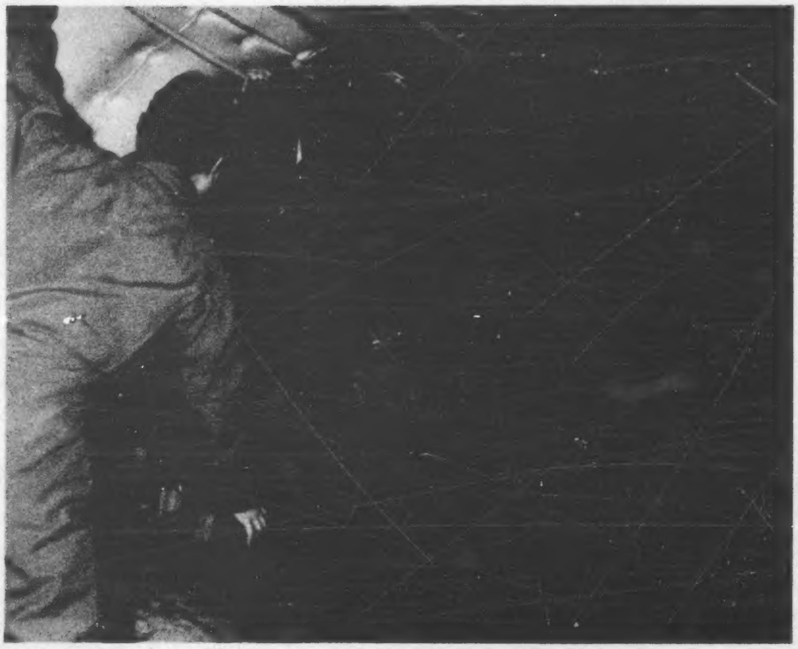
The distinction of being the first working scientist to walk on the Moon went to Dr. Harrison H. Schmitt, then 37, who became the last of the 12 U.S. astronauts who visited the Moon. The Apollo 17 flight in which he participated in December 1972 ended the six-flight series of Moon landing missions. Schmitt, who later served a term as a U.S. senator from New Mexico (1977-1983), had received his doctorate in geology from Harvard University in 1964, a year before he became an astronaut. He had worked for the Norwegian Geological Survey in Oslo, Norway, and for the U.S. Geological Survey (USGS) in New Mexico, Montana, and Southwestern Alaska and also for the USGS Astrogeology Branch as a project chief for photo and telescopic mapping of the Moon. Mainly because of this last experience he had been assigned by the USGS—before he himself became an astronaut—as an instructor for Moon-bound astronauts preparing for geological field trips and the collection of geological samples.

Medical Specialist Flown

The first American physician in space was Dr. Joseph P. Kerwin, then 41, who was a member of the first of three crews who visited *Skylab*, the house-size, 100-ton U.S. space station.

He and two astronaut companions lived in that station in orbit for 28 days from May 25 to June 22, 1973. Kerwin had been added to the *Skylab* crew because of the increasing awareness at that time of new opportunities for medical research in weightlessness which could contribute to the understanding of the human system on the Earth.

Skylab's roominess made possible thorough physical examinations of astronauts in orbit for the first time, and Dr. Kerwin took advantage of these opportunities to examine himself and his two astronaut colleagues in his studies of their physical responses to prolonged weightlessness.



Weightlessness is achieved for a few seconds inside a KC-135 *aircraft flying in a parabolic curve.* Spacelab-1 *Payload Specialist Dr. Byron K. Lichtenberg (in green clothes at right with left hand to ceiling) and his alternate, Dr. Michael L. Lampton (in blue clothes at top center), together with a Johnson Space Center physician, Dr. Joseph Degicanni (center), practice moving around in weightlessness with the help of technicians as part of the training for* Spacelab-1.

Until that time the effects of weightlessness could be determined only from descriptions by astronauts, from examinations of the crews immediately before and after a flight, and from some limited monitoring of certain body functions, such as the heartbeat, with tiny sensors taped to the chests of astronauts.

Kerwin and Schmitt had been among six scientists who joined the U.S. astronaut corps as a group in June 1965 to go into training as "scientist-astronauts." Also among those six was Dr. Owen K. Garriott (who is mentioned earlier in the chapter), a member of the second *Skylab* crew in the mid-1970s and now a mission specialist in the SL-1 crew.

Science Specialists Needed

The selection of science specialists came as a result of an increasing realization at the time that the ranks of the early test-pilot astronauts would have to be augmented by experienced scientists if the research opportunities of the new system were to be fully exploited.

The new scientist-astronauts had to abandon their scientific positions to enter full-time astronaut training at the Johnson Space Center. Each of them had to spend several years learning the operation and handling of spacecraft, and they had to share in spacecraft operational tasks and other in-flight chores as full members of the flight crew. The full extent of the preflight training required of scientist-astronauts is illustrated by the fact that Kerwin and Garriott had been full-time astronauts for eight years and Schmitt for seven years before they made their first space flights.

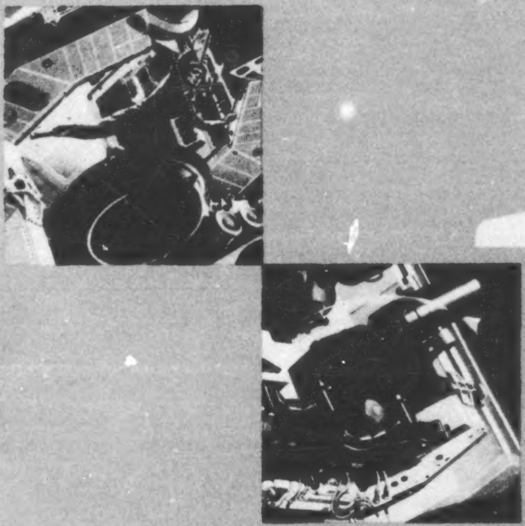
Training Time Reduced

In contrast, today's *Spacelab* payload specialists need to undergo only a brief training period. They are not expected to give up or to be away for very long from their positions in their research centers during their temporary training and work on a flight crew. Though the SL-1 payload specialists, being the first, had a longer training period, the time for the preparation of future payload specialists is expected to shrink eventually to about 100 hours. This preparation period includes the time necessary for their familiarization with the instruments on their assigned missions. This abbreviated training is expected to make it possible for NASA to recruit distinguished investigators for work in space who would not be willing to relinquish or substantially interrupt their scientific career positions.

Spacelab is a machine entirely dependent on human know-how and human direction. Notwithstanding their sophisticated automatic systems, the Shuttle and *Spacelab* are built to carry human crews and to be operated by these crews. Beyond its sensitive observation instruments and its other advanced research apparatus, *Spacelab*'s essential ingredients remain the intellect, judgment, and skills of the people who operate it. There is no substitute or near substitute for these qualities. *Spacelab* relies completely upon human performance for its ultimate success. The most important system aboard *Spacelab* is its crew.

“The purpose of the Agency shall be to provide for and promote, for exclusively peaceful purposes, cooperation among European States in space research and technology....”

From the convention at which the European Space Agency (ESA) was organized.



“[the National Aeronautics and Space Administration shall]... plan, direct, and conduct aeronautical and space activities... arrange for participation by the scientific community in planning scientific measurements and observations ... provide for the widest practical and appropriate dissemination of information concerning its activities and results thereof....”

From the U.S. National Aeronautics and Space Act which created NASA.

CHAPTER 4

Spacelab at Work

The Experiments (Part I)

Materials Science and Space Plasma Physics

Visible evidence of the tremendous energy arriving at and stored in the regions surrounding the Earth are sporadic occurrences of auroras, the ghostly northern and southern lights that dramatically illuminate the night sky. Spacelab *instruments are seeking to learn more about these energy releases and their still little-understood effect on conditions on the Earth.*

The treasures that astronauts bring to Earth from space are not of a material kind. They are far more precious because they are in the form of knowledge unobtainable elsewhere.

This statement, often heard in the early days of the space age, applies more appropriately to *Spacelab* than to any of its predecessors.

The quest for knowledge is *Spacelab*'s only task. All of *Spacelab*'s work is research. To extend the boundaries of science and technology is *Spacelab*'s sole assignment.

This is essentially true even for *Spacelab*'s early missions—SL-1 and SL-2—officially billed as "verification flights." Their prime objective is to check out *Spacelab*'s systems in orbit, test their compatibility with those of the Orbiter in space, and to confirm *Spacelab*'s suitability as host to the complicated experiments awaiting it. But these early flights are more than mere shakedown cruises or trial runs.

To give *Spacelab* the desired realistic tests, many complex experiments, from nearly every major scientific field, are aboard the very first flight.

Module-Pallet Configuration Flies First

SL-1 carries 38 separate scientific instruments* or "experiments packages," which the crew uses to perform more than 70 different experiments for more than 70 investigators who head research groups in 11 European countries,† the United States, and Japan. SL-1 will fly *Spacelab* in a basic configuration—the long module plus one pallet. Twenty-seven instruments are carried aboard the pallet, eight are installed inside the module, and three use both, with some components on the pallet and some inside the module.

Nearly all of these experiments have been in preparation for many years. For many of the investigators an important aspect of their careers is riding into orbit with *Spacelab*.

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* *NASA and ESA agreed to divide* Spacelab*'s weight capacity equally among themselves for their instruments. ESA's instruments are smaller and lighter. Thus ESA has 24 instruments and NASA 13 aboard SL-1. One instrument in plasma physics is being carried on SL-1 for Japanese researchers.*

†*The 10 European nations who jointly designed, built, and financed* Spacelab *plus Sweden.*

Many have invested substantial portions of their professional lives and research resources in the design and construction of these experiments.

That is why it is not surprising that Ulf Merbold, the European payload specialist aboard SL-1, gave this pledge to his science colleagues when he addressed some of them at the International Astronautical Federation Congress in Paris on September 28, 1982:

"I promise, on behalf of the entire payload crew," said Merbold, "that we all—be it in *Spacelab* or as backups or support crews on the ground—shall give our very best to assure good scientific return to the scientists who spent so much of their time, energy, and enthusiasm to develop their experiments."

Some SL-1 experiments require instruments to look down at the Earth for studies of lands, oceans, and the atmosphere. Others require instruments to look up at the Sun and stars. Some examine the immediate surroundings at *Spacelab*'s orbital altitude. And still other experiments take place inside the *Spacelab* module without any reference to outside conditions.

This contrasts with the experiment lists for some later *Spacelab* missions when an entire flight may be devoted to research in a single scientific discipline. Such "discipline missions" make it possible to focus all of a flight's resources and research strategies on specific research objectives.

In a discipline mission dedicated to Earth resources observations, the Orbiter can maintain its upside-down position (as seen from Earth) throughout the flight so that *Spacelab* observation instruments can look toward Earth continuously. In a mission dedicated to experiments requiring long periods of weightlessness or near weightlessness, the Orbiter can restrict its movements and remain floating undisturbed at a constant velocity through most of the flight. In an astronomy mission the Orbiter's cargo bay can be kept facing outward toward the celestial objects which are the targets of *Spacelab*'s research instruments.

In SL-1 the Orbiter intentionally engages in many maneuvers and position changes to satisfy the needs of the various experiments. The SL-1 list of experiments reads like a mail-order catalogue. The variety is deliberate. Some SL-1 experiments are designed to test *Spacelab*'s abilities as a stable observation platform for studying distant research subjects as well as closer ones.

Other SL-1 experiments will check *Spacelab* for its performance as a "test bed" for calibrating and appraising the usefulness of new instruments and processes. Still other experiments examine *Spacelab*'s utility as a laboratory for work in materials processing and life sciences investigations inside the module.

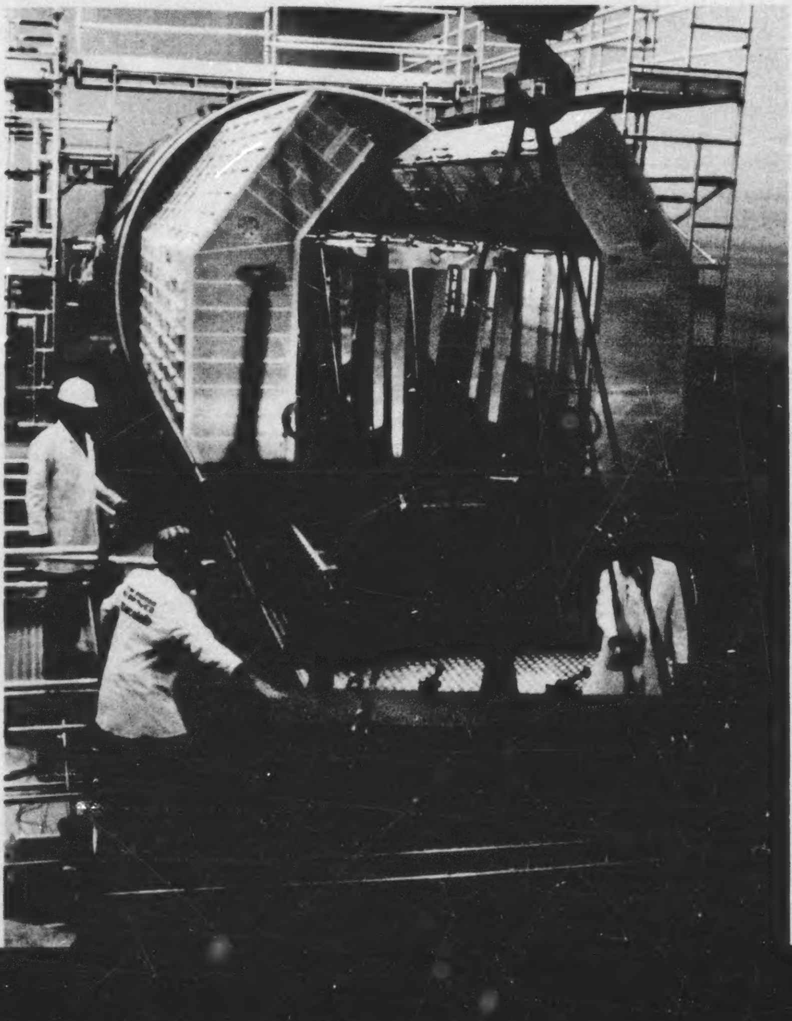
Space Provides Unique Opportunities

Experiments planned for *Spacelab* take advantage of one or more of the five unique properties of space—attributes which cannot be duplicated on Earth:

- Prolonged weightlessness (or long-enduring below-normal gravity);
- Sweeping, wide-angle, "picture window" views of very large regions of the Earth's surface;
- A view of the universe free from the obstructing atmosphere;
- A high, nearly complete vacuum;
- Access to "plasmas" and other phenomena in space near the Earth.

Mission planners have divided SL-1 experiments into five major categories (figures in parentheses show the number of experiments in each category):

- Materials Processing (also called Materials Science) (36)*;



Experiment racks manufactured in Italy sit ready to be installed in the Spacelab *module at the assembly plant in Bremen, West Germany, before shipment to the United States.* Spacelab *has been designed so that experiments can be placed in the racks before the racks are rolled into* Spacelab.

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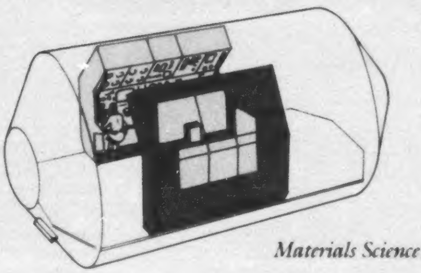
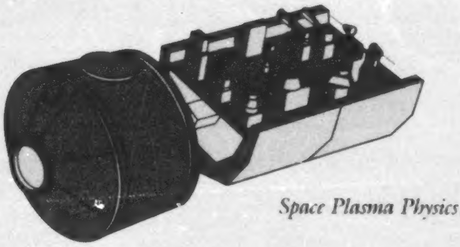
* *One of these is a "technology experiment."*

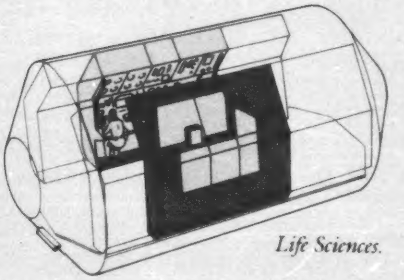
Typical Spacelab *Configurations for Discipline Missions.*



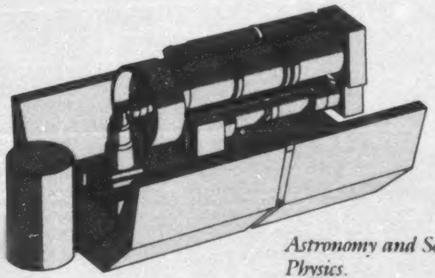
Materials Science.



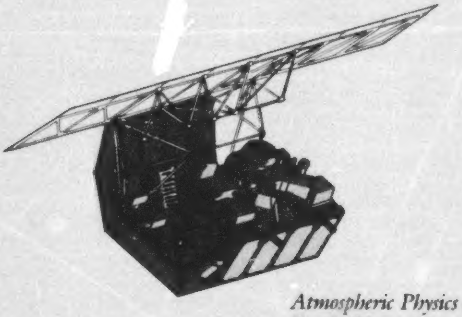
Space Plasma Physics.



Life Sciences.



Astronomy and Solar Physics.



Atmospheric Physics and Earth Observations.

- Space Plasma Physics (6);
- Life Sciences (15);
- Astronomy and Solar Physics (6);
- Atmospheric Physics and Earth Observations (6).

(Some experiments not counted above may straddle several categories. Several multiuse instruments provide data required for a variety of experiments. Conversely, some experiments may use data from more than one instrument.)

Materials Science

Thirty-five SL-1 *experiments—nearly half of the total on board—are in the field of materials science. Thirteen of these come from investigators in West Germany, eight are from France, four from the United Kingdom, three from Italy, two each from Austria and the Netherlands, and one each from Belgium, Spain, and Sweden. Also, a technology experiment by the United States is in the same group.*

The need for improved materials is universal. Engineers faced with a continuing trend toward miniaturization need alloys with changed conductivity and insulation characteristics for reliable, less costly communications and electronic equipment. Biomedical researchers seek lighter, stronger materials for sophisticated surgical instruments and new kinds of prostheses.

Automation of industrial machinery and household appliances calls for new kinds of alloys, plastics, ceramics, composites, and glasses with presently unavailable properties. Architects want structural materials that handle easily at reduced cost. They would be used for residential, commercial, industrial, and public works construction.

Whether any of these needs can be fulfilled with space technologies remains to be seen. *Spacelab*'s materials science experiments are descendants of very promising, but relatively primitive preliminary investigations begun on Apollo flights in the early 1970s. More ambitious experiments with a materials-processing chamber about the size of a large sewing machine were conducted aboard *Skylab* in 1973 and 1974. The new *Spacelab* explorations are more extensive and use more advanced and more sophisticated equipment. They may provide more definite answers.

All of these experiments share one premise: that in prolonged weightlessness or lower-than-normal gravity, materials can be manufactured with properties unobtainable on Earth, where weightlessness can be achieved for no longer than seconds at a time.

When a heavy and a light metal are heated, melted, and mixed on Earth, the heavier components settle before the mixture can be cooled to a solid state. In weightlessness in space the mixture remains uniform. Formerly incompatible substances can be combined into consistent new kinds of materials. Unevenly heated fluids remain still until they harden, free from the disturbing convection currents that normally drive the hotter, and therefore lighter, portions to the top while the cooler portions sink.

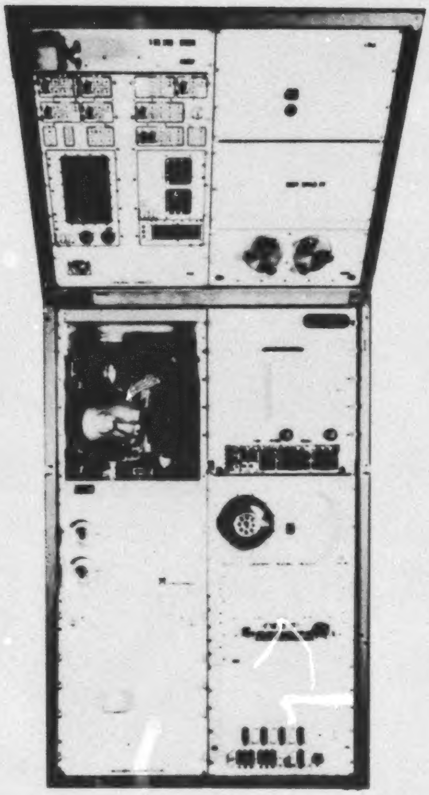
Materials Studied Early

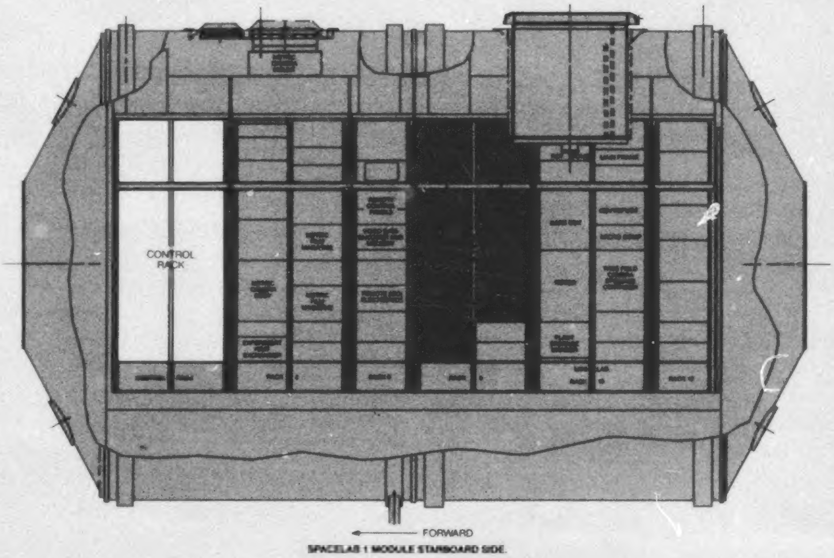
One of the earliest American in-space experiments in materials science took place on Sunday evening, February 7, 1971, on the home-bound leg of the nine-day Apollo 14 flight, history's third successful manned Moon-landing mission.

During a live color telecast from space, while the craft was nearing the Earth, the crew heated 18 sealed capsules containing a combination of ingredients, shook them briskly, then cooled them. One of the capsules contained paraffin, tungsten pellets, and sodium acetate. On Earth, gravity would have quickly separated the heated contents so that the heavier tungsten would have been on the bottom, the sodium acetate in the middle, and the lighter paraffin on top. In the nearly weightless environment of Apollo 14 the three ingredients retained their distribution to form a mixture never before achieved by civilization.

Results Prove Encouraging

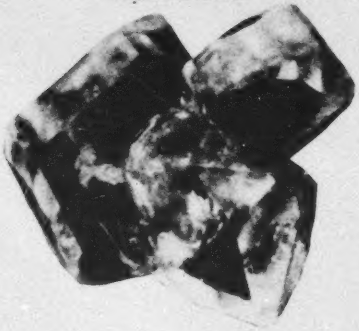
Similarly encouraging results emerged from the other capsules. Among the Apollo 14 materials experiments were three to test materials-separation techniques in weightlessness. One of these processes, called electrophoresis, is based on the fact that most organic molecules become electrically charged when they are placed in a solution. When an electric field is applied (through an electrode in contact with the fluid), the charged particles move toward the electrode. Because molecules of different sizes and shapes move at different speeds, the faster molecules in a mixture "outrun" the slower ones as they move from one end of the solution to the other. Particles that are alike tend to form into layers.

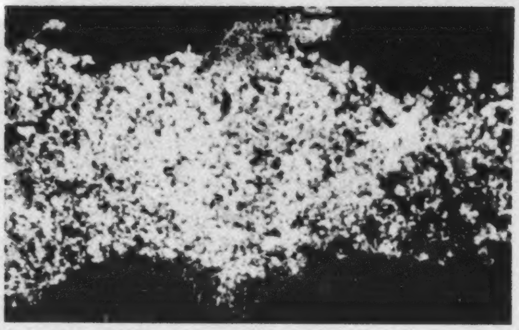




Close-up (top) shows double rack used for materials-science experiments. Diagram shows how this rack at far left fits into wall of module between other experiment racks. Small furnaces and process chambers in this rack liquefy, mix, and resolidify metals and other materials in weightlessness aboard Spacelab.

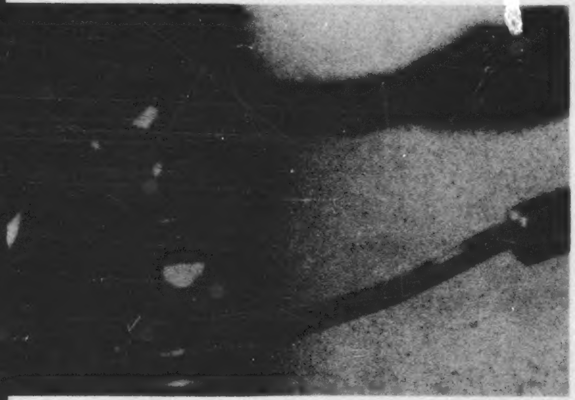
Crystal Growth.

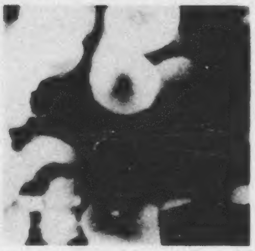


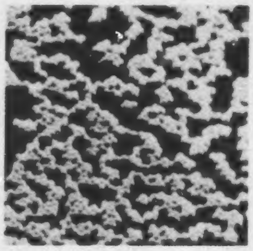


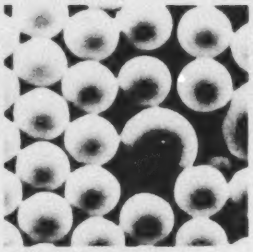
Solidification Casting.

Containerless Processes.

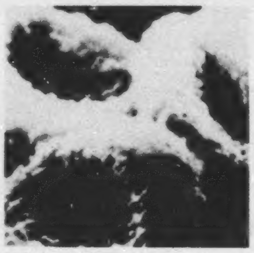






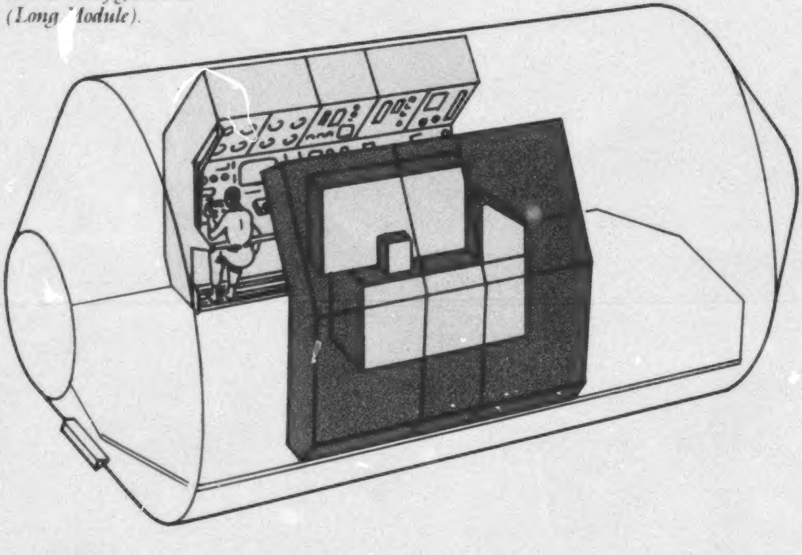


Chemical Processes.



Biological Separation.

Concept for Materials Science Configuration (Long Module).



Unwanted substances can be removed by taking out the layer in which they have accumulated. The process has been particularly useful in filtering biological products to prepare purer medical preparations and vaccines with fewer adverse side reactions. On Earth such separation is difficult or inefficient because the pull of Earth's gravity overpowers the electrode attraction. Technical problems made results from two Apollo 14 samples inconclusive. The third, a mixture of red and blue dyes, indicated the feasibility of obtaining sharper separations in space than is possible on Earth. Repetition of the experiments with improved demonstration apparatus during the Apollo 16 Moon-landing flight in April 1972 tended to confirm these findings.

Skylab Had Materials Facility

Materials processing in space made new strides aboard *Skylab* in 1973 and 1974 with a Materials Processing Facility that included a vacuum chamber 40 centimeters (16 inches) in diameter, inside which there was an electric furnace 29 centimeters (11.5 inches) long and 10 centimeters (4 inches) in diameter. With its ability to generate temperatures of up to 1,000 degrees C (1,832 degrees F) and to cool at controllable rates, the facility was used by astronauts to melt, weld, braze, and cast metals and alloys. This facility produced composite materials and formed them into spheres. The facility was also used for growing crystals in weightlessness. Several materials science experiments have already been conducted on Shuttle flights.

Spacelab's long module houses the Materials Science Double Rack Facility on the first flight. It stretches from the module's floor to the ceiling and accommodates four furnaces and processing chambers. After loading prepackaged cartridges containing sample materials into the processing chambers, crew members operate the controls to apply heat for as many as 30 separate experiments.

One of the furnaces, the Isothermal Heating Facility, retains its temperature at a constant level through each experiment. Two cartridges can be processed simultaneously, one heating while the other cools. This furnace will be used for studies of the solidification of metals and alloys and for forming composites. Improved glasses and ceramics are additional possibilities for this unit.

The Gradient Heating Facility is designed for studies of crystal growth, and the Fluid Physics Module for studies of behavior of fluids in weightlessness. In the absence of gravity, liquids do not necessarily sink to the bottom of a tank or flow through its floor outlets. Nor are heated fluids disturbed by convection currents in their weightless state.

Two mirrors in the Mirror Heating Facility in the double rack concentrate heat from a filament on a single point or limited region—in contrast to the other furnaces which heat an entire processing chamber.

Besides SL-1 experiments accommodated by the four furnaces, six other experiments in this group require their own special instruments.

Lubricants Study Planned

One of these is a technology experiment, called Tribology in Zero Gravity, which is the only United States investigation in this group aboard SL-1. Jointly sponsored by Columbia University and NASA's Marshall Space Flight Center, this experiment seeks to find out how lubricants spread in the absence of gravity and how their changed behavior in weightlessness may affect friction and wearing of moving machine parts. Tribology is the study of the effect of moving surfaces on each other. A payload or mission specialist applies lubricants and then photographs their movement and distribution on stationary as well as on moving surfaces. Experiment findings could influence future machine designs, particularly equipment for use in space.

Two other SL-1 experiments deal with adhesion and diffusion of metals, and three others with crystal growth in weightlessness. The possibility of in-space growth of flawless crystals intrigues many scientists and engineers. Crystal formation, like metallurgy and other materials processing, is subject to three major forces—heat, pressure, and gravity. The first two are easily produced and controlled as desired. Adverse effects of gravity are beyond control on Earth except under certain special circumstances, such as in free fall or in certain flight paths in an airplane. On Earth, elimination of gravitational influence is possible for only seconds at a time.

Gravity-induced convection in chemical solutions almost invariably causes defects and malformations during crystal growth. Mass-produced crystals free of imperfections, apparently feasible in space, could lead to lower-cost and higher-performance communications and electronics instruments and set off another technological revolution in these already high-technology industries.

Similarly, the prospect of new kinds of glasses formed in weightlessness that would lend themselves to near-perfect, distortion-free lenses has led experts to envision a new age of optical products for industry and consumers.

Containerless Processing Foreseen

Optimistic forecasters foresee the possibility of containerless processing. Some experiments in that technology have already been conducted on board Shuttle flights and are planned for later *Spacelab* flights. Metals and other molten materials would cool and resolidify while floating weightlessly in a vacuum without touching any floor, wall, or other part of conventional containers.

Such a technique is foreseen as the ultimate in contamination-free processing,

Familiarizing himself with the experiments in the laboratory racks in the Spacelab *module is Payload Specialist Dr. Byron K. Lichtenberg, whose responsibility on the first* Spacelab *flight will be conducting many of these experiments.*

because contact with any container, however slight, causes unwanted temperature changes and materials transfer.

As now envisioned for future *Spacelab* materials-science research, teardrop-size samples of metals and other materials will be held suspended without visible support and kept from drifting by sound waves trained on them from above, below, and the sides. If a sample tended to drift in any direction, the "accoustical levitator" in that area would automatically increase its output of sound waves to push the sample back into place. Also, varying the intensity of the sound is expected to make it possible to shape the liquid to desired forms. Sound waves on the Earth lack sufficient strength for such action against the force of the gravity pull, but they exert sufficient pressures to hold weightless specimens in their position in a vacuum. While suspended, the samples would be heated, mixed, or otherwise processed, cooled for resolidification, and returned to Earth for analysis.

Foamed Alloys a Possibility

Foreseen too are "foamed alloys" with bubble-like tiny pockets, like those in a sponge. Theoretically they could be stronger than steel, yet lighter than balsa wood. In any attempt to make such materials on Earth, the pockets would collapse before the material could solidify sufficiently during cooling.

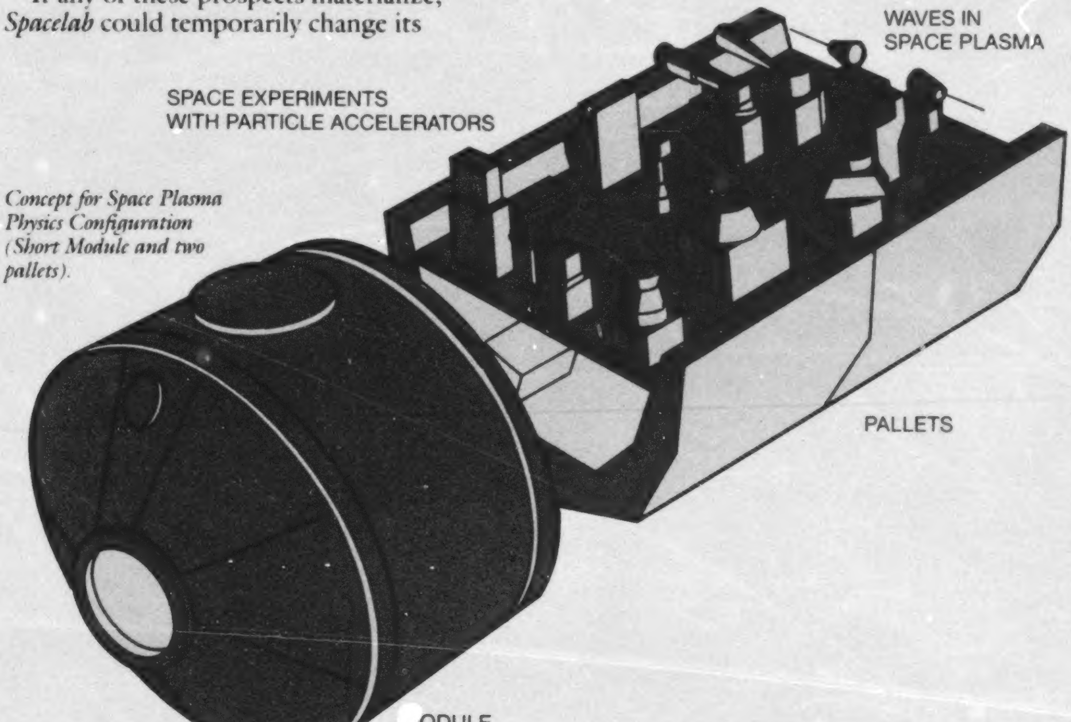
If any of these prospects materialize, *Spacelab* could temporarily change its character as an exclusive research facility and become an interim manufacturing facility for small quantities of these valuable materials. Thus *Spacelab* could become a forerunner of our first factories in orbit, delivering the first commercial products stamped "Made in Space."

Of all *Spacelab* experiments, those in the materials science category are perhaps the most easily understood by nonscientists and are most likely to benefit large numbers of people in the near future. The space plasma physics experiments, which are discussed next, are among the most intricate *Spacelab* work from the point of view of nonscientists.

Space Plasma Physics

Six experiments aboard SL-1*—two from West Germany, and one each from Austria, France, Japan, and the United States—will investigate the processes that occur around the Earth immediately above the atmosphere in the regions through which* Spacelab *is traveling. These experiments are grouped under the category of space plasma physics.*

In the last 20 years scientists have radically changed their concepts about the environment of the Earth above the atmosphere. No longer do they visualize the Earth as traveling through a void, merely being warmed, as it turns, by the visible radiations from the Sun.


WAVES IN SPACE PLASMA
SPACE EXPERIMENTS WITH PARTICLE ACCELERATORS
PALLETS
ODULE

Concept for Space Plasma Physics Configuration (Short Module and two pallets).

Observations by spacecraft in the last two decades show that the Earth is plowing through an active, energy-flooded environment in its annual orbit around the Sun. The near vacuum of space contains dynamic forces whose effects on our own environment at the Earth's surface are only beginning to be understood.

Magnetic fields envelop the Earth. Energetic particles strike the upper atmosphere. Visible and invisible radiations from the Sun and far more distant sources stream toward Earth. Electrified gases, called plasmas, flow past at speeds of up to 1,000 kilometers per second (625 miles per second).

The impact of these processes on our lives is only vaguely known, though there is evidence that these powerful forces so near the Earth generate important electrical and physical phenomena in our atmosphere and quite possibly influence our weather.

We know that bombardment of our upper atmosphere by charged particles from the Sun, guided along the Earth's magnetic force lines, can cause luminous bands called auroras, which can be seen sporadically in Earth's polar skies. Disturbances in these regions, caused by violent Sun behavior, can interfere with shortwave radio communications and interrupt electric power transmission on Earth.

Instruments to Study Auroras

Six instruments, each designed for investigations studying forces related to auroras, are mounted on the SL-1 pallet. One of these instruments consists of two units, one of them in the scientific airlock. Scientists hope to coordinate the data obtained from these instruments with the results from collaborative studies now in progress.

A large instrument, known as SEPAC (Space Experiment with Particle Accelerators), developed for this mission by Japan's Institute of Space and Astronautical Science in Tokyo, injects gas streams and high-intensity electrons from its position on the pallet into Sun-ejected plasmas trapped in Earth's magnetic field. The results of SEPAC injections in space are analogous to radioactive tracers in medical research. They trigger radiant emissions that are essentially man-made auroras. SEPAC and other SL-1 instruments observe these illuminated beams that tend to travel along magnetic field lines, the normal route for energy entering the atmosphere.

The SEPAC instrument, controlled from the *Spacelab* module by payload and mission specialists, is the only SL-1 experiment by a Japanese research team.*

A French experiment, called Phenomena Induced by Charged Particle Beams, sends moderate-intensity particle beams into the

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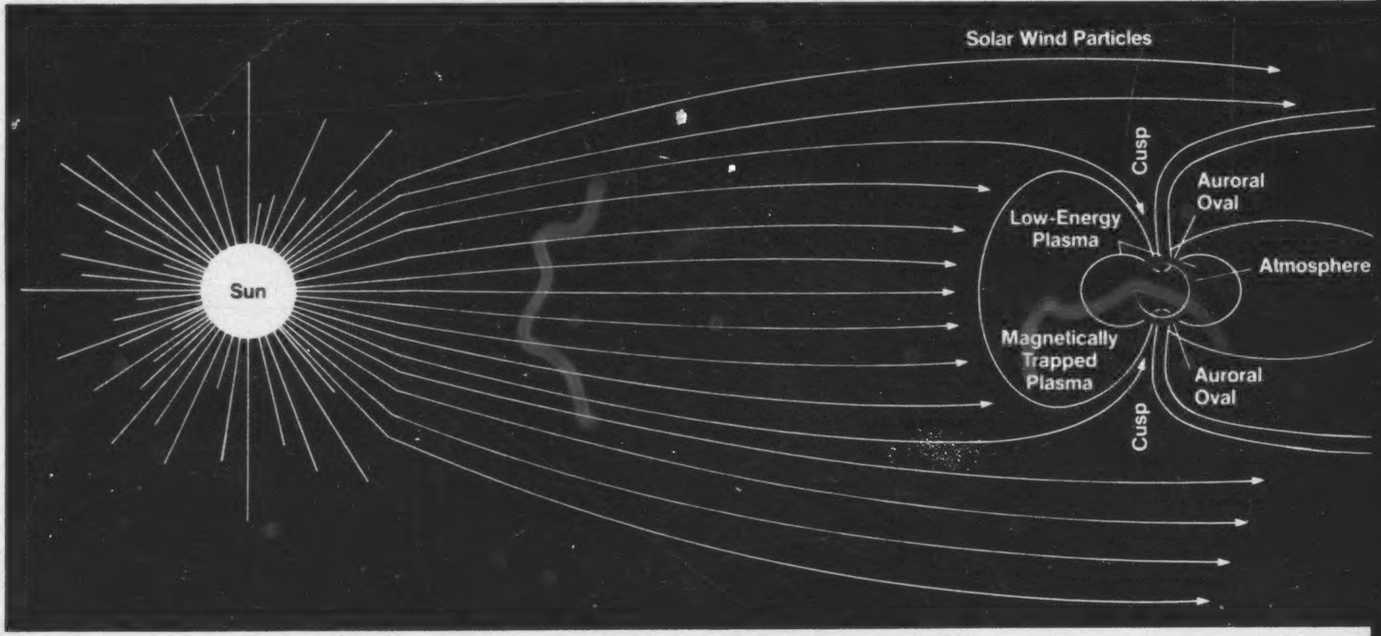
**Japan is also planning for a partial* Spacelab *mission in 1988 for material and life sciences experiments. This mission will be on a cost-reimbursable basis— Japan pays* NASA *for the applicable expenses of operating the flight—and Japan may perhaps send its own payload specialist along.*



The regions surrounding the Earth were once considered a void, with only visible sunlight warming the atmosphere and the surface. That view has changed as scientists in recent decades have discovered magnetic fields which trap electrified gases called plasmas, emitted by the Sun and enveloping the Earth beyond the denser portions of the atmosphere. Experiments aboard Spacelab *will examine these phenomena, which are not readily detectable or measurable from lower altitudes.*

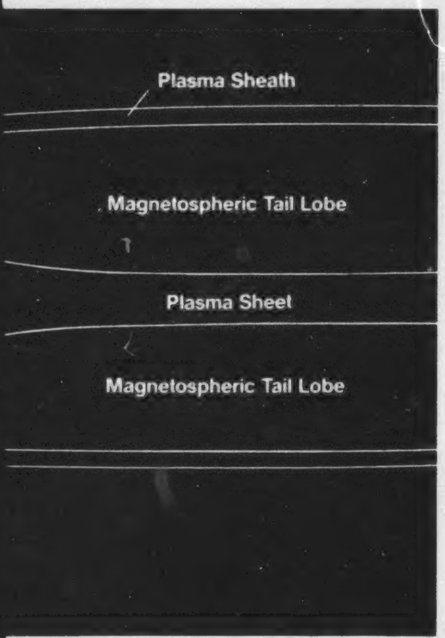


Diagram shows Earth's Magnetosphere and other near-Earth phenomena.

plasma. These beams, generated by the instrument's "active" unit on the pallet, trigger a reaction from the plasma, which is measured by the instrument's "passive" unit mounted in the module's scientific airlock. Payload and mission specialists install the passive unit in the airlock and operate the experiment for the French National Center of Scientific Research.

A passive experiment from the Max Planck Institute for Aeronautics in West Germany, called Low Energy Electron Flux, uses a pallet-mounted detector to trace "echoes" reflected from electric fields by the electrons fired by the above two active instruments.

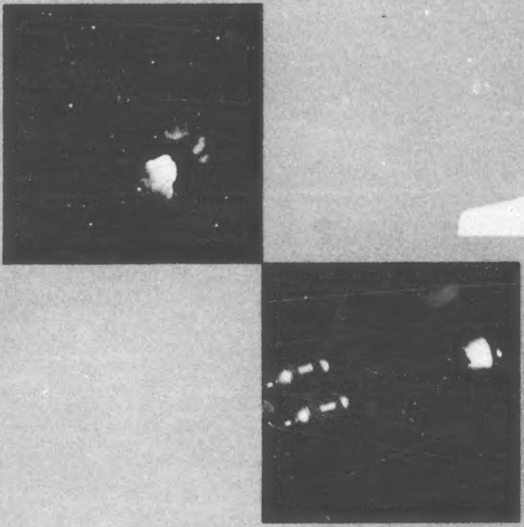
Among three other passive experiments on the SL-1 pallet is the Atmospheric Emission Photometric Imaging instrument from the Lockheed Palo Alto Research Laboratories. It uses television and a photometer to observe the artificial auroras. *Spacelab*'s on-board computer controls most of the operation of this largely automated experiment.

Another passive experiment analyzes the magnetic field around the Orbiter. This experiment, called the DC Magnetic Field Vector Measurement, is from the Space Research Institute of the Austrian Academy of Sciences. The experiment uses three magnetometers to measure different aspects of the motions of particles along the lines of Earth's magnetic field. From these motions the instrument calculates the strength and direction of the magnetic field.

The last of the passive experiments in the plasma physics series on board SL-1 is the Isotope Stack Measurement of Heavy Cosmic Ray Isotopes. It is a detector made up of a series of plastic sheets stacked on top of each other behind a thin shield. Cosmic rays passing through the sheets or being stopped by them leave tracks, revealed after chemical processing of the sheets following the flight. From analysis of these tracks scientists can determine the strength, speed, composition, and even the source of these particles. The experiment is from the Institute for Basic and Applied Nuclear Physics of the University of Kiel, West Germany.

Though some of the research appears intricate and complex, the bottom line for *Spacelab* investigators is simple: To what extent is the research expanding human knowledge? How well is *Spacelab* helping to put knowledge to work for human betterment and progress? *Spacelab*'s payoff ultimately lies in the answers to these questions.

"This facility, a product of international cooperation on a large scale, is available today for the science and application community. NASA *and* ESA *are currently integrating the first* Spacelab *payload and flight system leading to its initial flight in October 1983. This event will mark the start of a new era in space utilization and investigation. The remaining challenge will be the imaginative and beneficial use of this unique facility."*



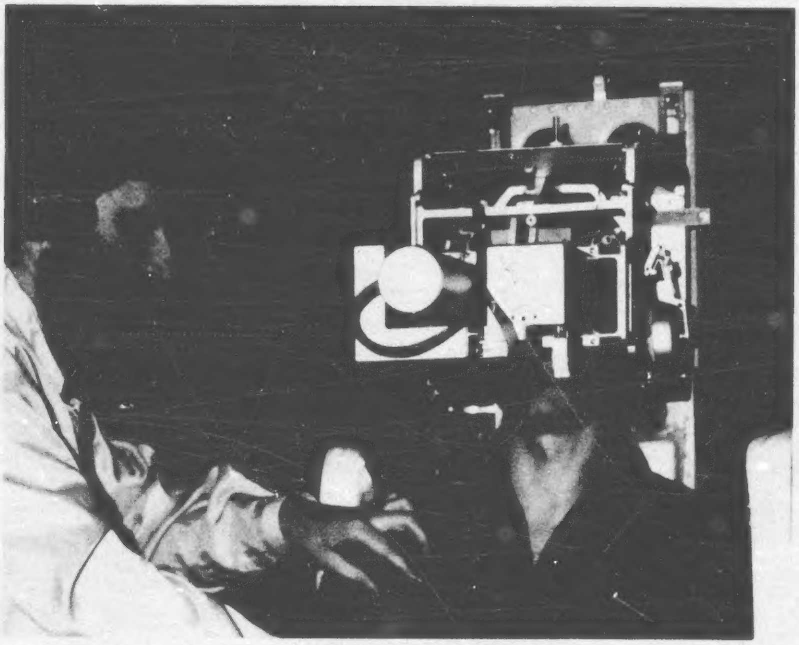
From a paper presented by James C. Harrington, NASA *Spacelab* Division Director, March 18, 1982.

CHAPTER 5

Spacelab at Work

The Experiments (Part II)

Life Sciences, Astronomy and Solar Physics, Atmospheric Physics and Earth Observations



The face of Spacelab-1 *Payload Specialist Dr. Ulf Merbold is partly hidden by the strange headgear used in experiments for exploring the effects of weightlessness on the balancing organs in the inner ear. This "helmet" shown here during ground training is to be used during the first* Spacelab *flight in life sciences investigations.*

Life Sciences

Not from Mars. Not from Jupiter. Certainly not from any flying saucer. What makes these space travelers look unlike Earthlings is the strange headgear they are wearing. Fold back the face plate and behind the forbidding exterior appear the familiar faces of the SL-1 payload specialists. They take turns donning a unique helmet containing "visual stimulation and recording devices."

The SL-1 payload specialists, on board *Spacelab* to conduct scientific experiments, also serve as prime research subjects themselves in several of the 15 on-board life sciences experiments. With the help of the mission specialists they conduct research on themselves and on each other.

Throughout the flight, from launch through landing, each payload specialist wears a standard battery-powered medical recorder on his belt. Wires from the recorder run to small electrodes glued to the head and chest. The electrodes monitor heartbeat, eye movements, and the electrical activity of the brain.

Upon return to Earth, scientists correlate each section of the recordings with the wearer's activities in space at the time the recording was made. Researchers are particularly interested in the recordings during launch and reentry and during sleep in weightlessness.

Similar measurements have been made of crews on earlier space flights. What is different this time?

"In the past, personnel exposed to prolonged weightlessness were a select group of astronauts," earthbound scientists emphasize. "Now the people who will go into space in *Spacelab* are more representative of the general population in age, physical fitness, and previous stress exposure. Nothing is known yet about the physiological reaction of this 'normal' population to the stress of space flight. We want to collect physiological data on normal people in an abnormal environment—in this case, the payload specialists in weightlessness."

The information they gather may become the basis for later studies, particularly when payload specialists of almost any age and from very different backgrounds are allowed to fly in orbit on future *Spacelab* missions. The information could become a guide for crew selection and for planning in-orbit activities. The scientists who sponsor this experiment and who will analyze the recordings are from the Clinical Research Center in the United Kingdom and they call their instrument the Personal Miniature Electrophysiological Tape Recorder.

Backpack Experiment Unique

Payload crew members will occasionally take turns wearing a backpack containing devices which measure the tiny body vibrations caused by natural processes.

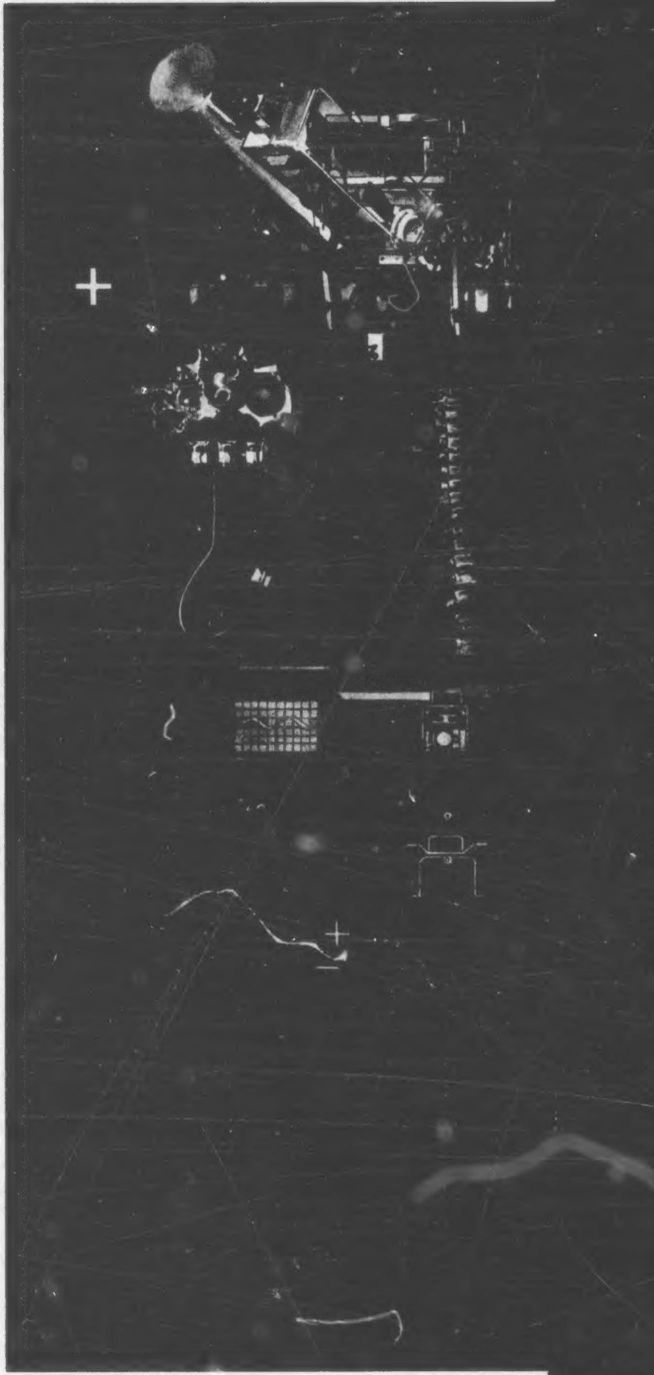
"Just as a pistol recoils when it fires, the human body reacts to each heartbeat with little movements," Italian scientists from a research team at the University of Rome who will analyze this experiment's results have stated. They will compare the readings made while the crew members are floating freely in weightlessness in orbit with recordings made of the same crew members on the ground before and after the SL-1 mission. The backpack contains an electrocardiograph (EKG) and three small accelerometers for measuring movements in three dimensions. These are usually very difficult to chart under the influence of gravity on Earth. The experiment is called Three-Dimensional Ballistocardiography in Weightlessness.

Four experiments—two from the United States and one each from Switzerland and West Germany—require taking blood samples from crew members before, during, and after the flight. Comparison of the samples is expected to show whether any reduction of disease-fighting antibodies occurred during weightlessness. Experimenters will be watching for reductions in antibody-producing lymphocytes and of hormones in the blood, as well as a lessening of the quantity of blood in crew members. These experiments also require in-flight measurements of blood pressure in arm veins to determine shifts of fluids to the upper body. All of these changes have been observed in crews on earlier space flights. Why and how these changes take place in weightlessness is only vaguely understood.

Weight-Guessing Game Planned

In another experiment the payload specialists and mission specialists play a 20-minute game. From a box containing 24 small steel balls they remove 2 balls at a time and judge which ball in each pair would be the heavier on Earth. All of the balls are of the same size, but on Earth each has a different weight. The difference is not easy to discern in weightlessness. Recorded answers

This rack, which is about to be installed in the Spacelab *module, houses life-sciences experiments. Racks like this one, filled with experiments and auxiliary equipment, line the inner walls of the* Spacelab *modules.*



©National Geographic Society
Painting by Roy Andersen

by the crew are expected to help scientists determine how well each member adapts to making certain judgments in weightlessness and to what extent weight differences can be appraised in orbit. The test, called Mass Discrimination During Weightlessness, was designed by researchers at the University of Stirling, United Kingdom. Performance in weightlessness will be compared with results from the same test upon return to Earth to detect how rapidly crew members readapt to normal gravity.

The visual stimulation and recording helmet mentioned at the beginning of this chapter is one of three pieces of research equipment used by the crew for several experiments that are among the most important on board SL-1. All three items are meant to help scientists learn more about the human body's gravity-sensitive organs in the inner ear. Disturbances of these organs—the otolith and vestibular organs—are believed to be responsible for the space motion sickness which has plagued about half of the people who have gone into space.

During brief periods of weightlessness in an airplane flying in a parabolic curve, Spacelab *Mission Specialist Dr. Robert A.R. Parker (in blue outfit) and technicians (in orange outfits) watch* Spacelab *Payload Specialist Dr. Ulf Merbold (in green outfit with shoulder straps) going through a test that measures the response of the inner ear's balancing mechanism to the absence of gravity. Scientists are particularly interested in finding out how to prevent motion sickness, which in orbit is called space adaptation syndrome.*

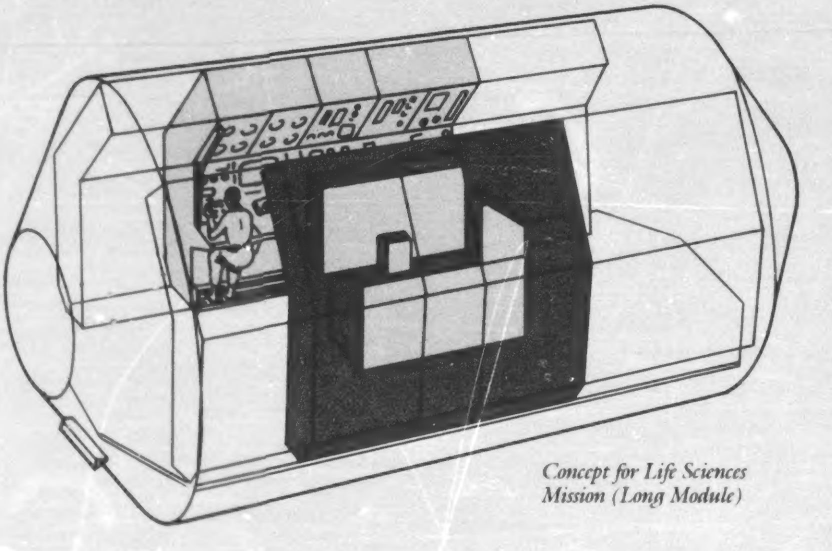
Will Study Motion Sickness

Pinpointing the cause and finding methods for preventing or lessening space motion sickness are major objectives of SL-1's science program.

Known by NASA medical people as "space adaptation syndrome"—and on Earth variously as sea, air, or car sickness—the illness causes rapid breathing, profuse salivation, cold sweat, and feelings of apprehension, general discomfort, and nausea.

The unique helmet is engineered to project various images to the wearer's eyes, giving him his only visual clues about his body's position. The experiment is conducted while the wearer floats in weightlessness inside the *Spacelab* module. Restraint devices prevent him from touching walls, floor, ceiling, or other objects that might help him orient himself. His only indications of his position come from helmet-generated images and from orientation organs in his inner ear. If clues from these two sources disagree, disorientation and motion sickness may result.

Designed by researchers at the Johannes Gutenberg University in West Germany, the helmet is used for an experiment conducted by a team at the German university as well as a team at the Massachusetts Institute of Technology and in Canada. Dr. Byron K. Lichtenberg, an SL-1 payload specialist, is a member of the MIT team which prepared this experiment for analyzing the brain's adaptation to the unusual conditions in weightlessness. A related equipment item,



Concept for Life Sciences Mission (Long Module) from researchers at NASA's Johnson Space Center, detects changes in spinal reflexes and posture when weightlessness disturbs the body's usual means of orientation.

SL-1 crew members will not be the only living organisms aboard *Spacelab*. In other life sciences experiments, dwarf sunflower seedlings are videotaped at different stages of their growth. Scientists want to observe the directions in which plants will grow when there is no gravity to indicate the direction of "up." In another experiment a fungus grows in total darkness so scientists can determine whether absence of gravity as well as normal day-night cycles cause changes in fungi's 24-hour growth cycle. The fungi's customary growth changes are governed by a 24-hour cycle called "circadian rhythms" believed to be triggered by day-night clues or other subtle environmental changes. Or it may be due to internal mechanisms unaffected by any exterior happenings. This experiment was prepared by the State University of New York at Binghamton.

Life sciences experiments, second in number only to materials science experiments on SL-1, will continue to receive high priority on future *Spacelab* flights. Two scientist-astronauts, Dr. Norman E. Thagard and Dr. William E. Thornton, both physicians, have been assigned as mission specialists to *Spacelab*'s third flight, expressly for continuing research on the space adaptation syndrome. NASA wants to learn whether it will be possible to identify persons who are particularly vulnerable to it, whether its onset can be predicted, and what countermeasures can be taken against it. The SL-3 flight—(STS-18)—will include experiments in materials processing, space technology, and life sciences.

Dr. Thagard conducted extensive research on the problem while assigned as a mission specialist on STS-7 in June 1983, as did Dr. Thornton as a mission specialist on STS-8 in August 1983.

Still more extensive research on space motion sickness and a variety of other medical and biological subjects is planned on the fifth *Spacelab* flight (SL-4) which is the first discipline mission entirely dedicated to life sciences research. Twenty-four experiments on that flight will cover a wide range of medical and biological subjects aimed at safeguarding human health in space, using the orbital environment to advance knowledge in medicine and biology and using space technology for solutions of medical and biological problems on Earth.

Life science experiments will also be a large part of the D-1 German mission payload.

Astronomy and Solar Physics

Six instruments aboard SL-1 are designed for studies of the Sun and stars. These instruments examine radiations which cannot penetrate the Earth's atmosphere and, therefore, cannot be studied from the ground.

Three of the instruments—one each from the United States, France, and the Netherlands—examine radiations from the stars. Three other instruments—one each from the United States, France, and Belgium—study radiations from the Sun.

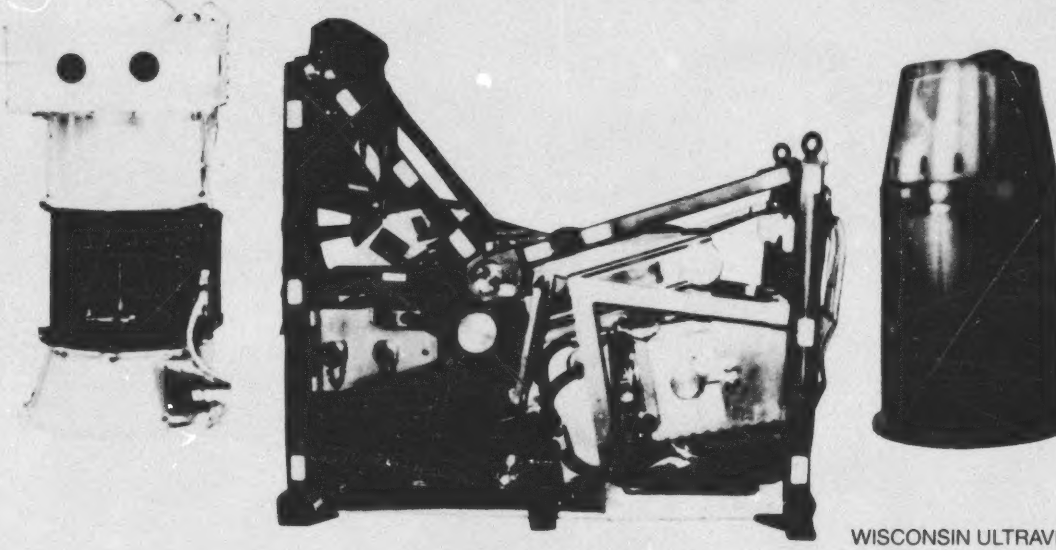
One of the instruments—the French star camera—is mounted in the airlock in the experiment module. The other five instruments are mounted on the pallet.

Newer and better instruments to delve deeper into the mysteries of the universe continue to emerge, and *Spacelab* is sampling some of them on its first flight. All of them exploit the obvious advantage of observation from orbit: the absence of the Earth's obstructing atmosphere. Researchers expect that in the relatively few days available for experiments during *Spacelab*'s flight, more and better observations can be made than would be possible in several decades from the Earth.

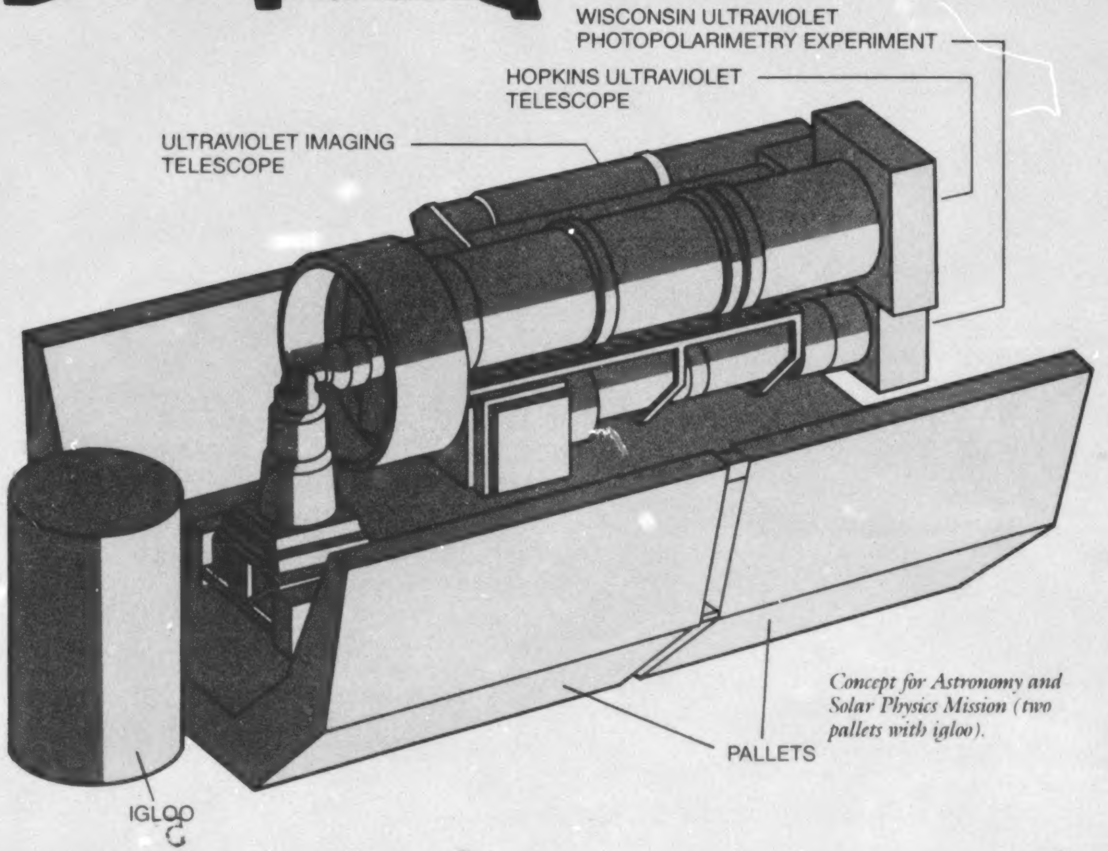
Among the most important research subjects in the life sciences aboard Spacelab *are the crew members themselves. Scientists want to know more about the human system's responses to prolonged weightlessness. In the simulated experiment shown here in the* Spacelab *trainer in Building 36 at the Johnson Space Center in Houston, Scientist-Astronaut Story Musgrave operates instruments monitoring Dr. Charles F. Savin, reclining, a researcher at the Center who is posing here as a research subject.*

Not only do observations from orbit guarantee cloudless, haze-free viewing, but instruments there have access to that majority of radiations from stars and other celestial objects which cannot penetrate the Earth's atmosphere and therefore are unobservable from the ground. Only a small segment of radiations in the electromagnetic spectrum reaches low altitudes or the Earth's surface. Most radiations are filtered or absorbed by the upper atmosphere.

Even for detection of those radiations which can reach the ground—including visible light—the atmosphere poses a persistent handicap to scientific sky watchers. Ever-present water vapor and dust distort or block incoming radiations. Debris from volcanic eruptions often remains in the upper atmosphere for several years. Added to these natural hindrances are such synthetic impediments as smoke, smog, and electronic interference. Light from cities often overwhelms faint star light. Many astronomers consider themselves fortunate if in the course of a year they obtain several hours of good viewing.



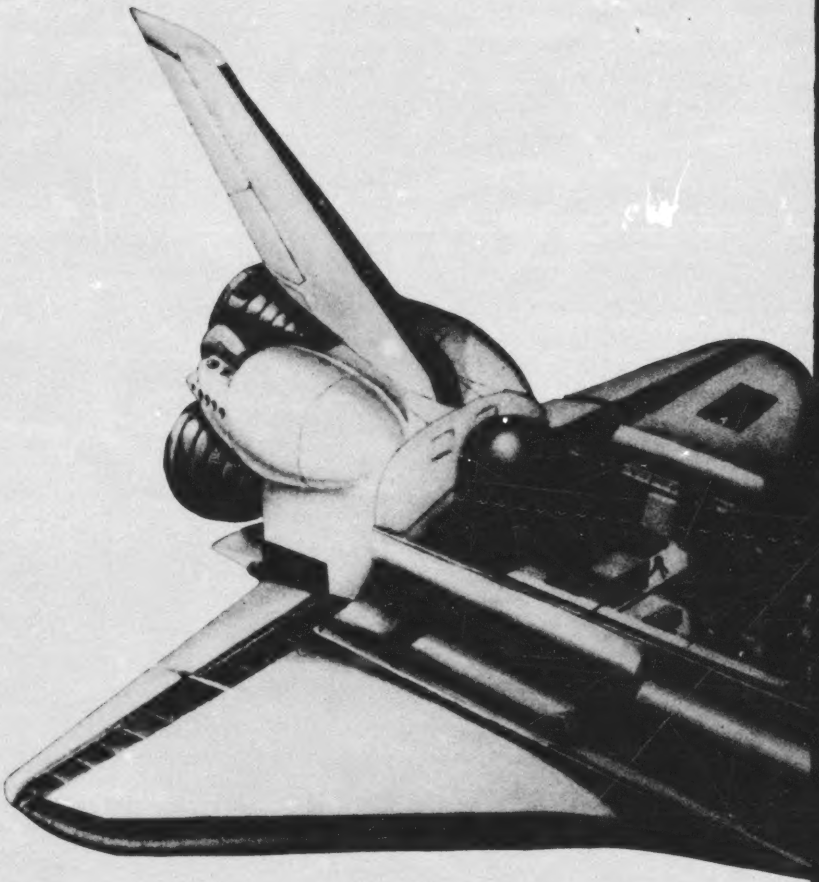
Spacelab *telescopes and other astronomy instruments are expected to provide more ideal viewing time in a few days than astronomers usually obtain in several decades of Earth-based observations. Three astronomy instruments aboard the first* Spacelab *flight are (from left) the X-Ray Detector, the Very Wide-Field Camera, and the Far Ultraviolet Telescope.*


WISCONSIN ULTRAVIOLET PHOTOPOLARIMETRY EXPERIMENT
HOPKINS ULTRAVIOLET TELESCOPE
ULTRAVIOLET IMAGING TELESCOPE
PALLETS
IGLOO

Concept for Astronomy and Solar Physics Mission (two pallets with igloo).

Space technology has opened a huge new window to astronomy. Not surprisingly, astronomical instruments were among the first scientific sensors to be attached to the earliest space rockets. Instruments on early sounding rockets made important astronomical discoveries. They detected stars emitting X-rays which are not detectable from the ground. These achievements are especially remarkable since these instruments remained above the atmosphere for only a few minutes before falling back to Earth. Since then many satellites have been outfitted with astronomical instruments, and astronauts on manned space flights have made valuable observations.

Beyond satisfying curiosity about the nature of our universe, astronomy research could produce many practical results. For example, the processes by which quasars and pulsars produce vast quantities of energy remain unexplained. Understanding them could lead to new energy-generating techniques that could provide inexhaustible and inexpensive energy supplies on Earth. Astronomical observations in the 16th and 17th centuries helped originate theories leading to some of the mechanisms that made possible the Industrial Revolution of the 18th and 19th centuries that still influence our lives today.

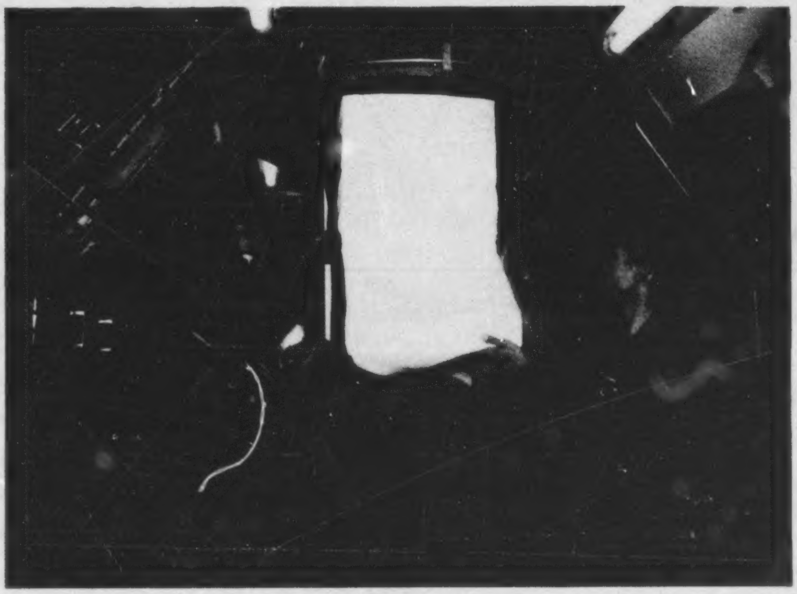


Astronomy Studies Planned

Having astronomers at work in space and operating an observatory there is one of the main purposes for building *Spacelab*. The third *Spacelab* flight—SL-2—has a large part of the mission devoted to astronomy. Its 13 major experiments are entirely devoted to astronomy and Sun research, including infrared astronomy, solar physics, and plasma physics.

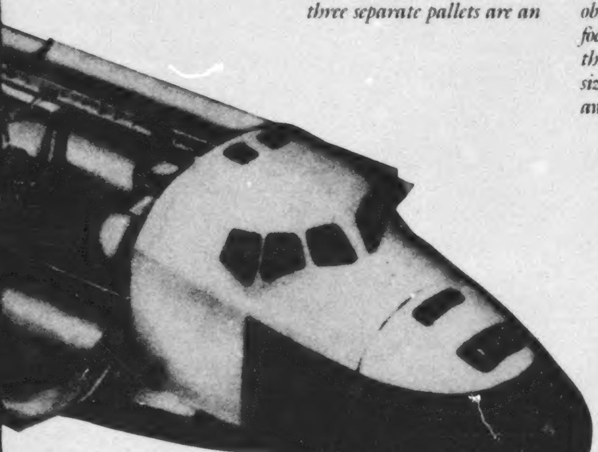
Scientists call SL-2 a "super mission," because its experiments call for the largest and heaviest astronomy instruments ever taken into space. Transporting equipment of such size and weight into orbit was impracticable or impossible until Space Shuttle.

A special structure will be installed in the shuttle cargo bay to support a dome-topped two-ton cosmic ray detector. With its



Spacelab-1 *Payload Specialists Dr. Byron K. Lichtenberg (right) and Dr. Ulf Merbold (center) and Dr. Michael Lampton, backup, unstow and mount the Very Wide-Field Camera during training at the Marshall Space Flight Center in Huntsville, Alabama. The camera, which will survey vast regions of the sky, is inserted into* Spacelab*'s airlock during the flight as shown here.*

rounded top it appears like a giant boiled egg in a holder, at the extreme back of the cargo bay. In front of it on a pallet rests a telescope specializing in infrared observations. Ahead of it, on another pallet, is a telescope for observation of X-ray emissions from celestial sources. And ahead of it, on a third pallet, are four Sun telescopes guided by the new Instrument Pointing System (IPS), which will be making its first flight.



Spacelab-2 *Configuration: The egg-shaped instrument in the rear of the cargo bay is a two-ton Cosmic-Ray Detector held in place by a specially designed support system. In front of it on three separate pallets are an Infrared Telescope, an X-Ray Telescope and four Sun Telescopes. The Sun Telescopes are being guided by the new one-ton Instrument Pointing System (IPS), which can hold observation instruments focused so accurately that they could observe a dime-size coin 2¼ miles (3½ km.) away.*

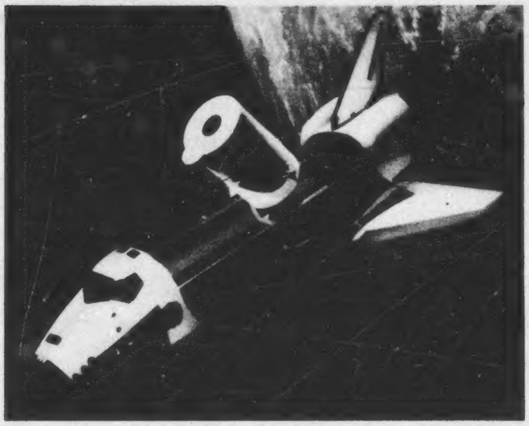
Igloo to Supply Pallets

Three pallets will be used simultaneously for the first time on this mission. It requires no habitable module because all of the experiments aboard can readily be controlled by payload and mission specialists from the Orbiter's flight deck or remotely from the ground. To house various items of equipment which would otherwise be inside a module because they require a normal atmosphere or moderate temperatures, an igloo will be installed ahead of the front pallet.

SL-2 was originally expected to be the second *Spacelab* flight, as its designation clearly indicates. Delays in the completion of the one-ton IPS, a very complex precision instrument designed as an aid for orbital astronomy observations, caused SL-2 to be postponed to March 1985, so that it will take place later than SL-3, now scheduled for September 1984. Despite this transposition, flight officials have decided to retain the SL-2 and SL-3 mission numbers as they were originally assigned.

SL-3, also a dedicated mission—meaning the Orbiter's facilities are exclusively devoted to *Spacelab*—is the first operational *Spacelab* flight in which the primary objective is the acquisition of scientific data rather than the testing and verification of *Spacelab* systems.

Many of SL-3's major experiments take advantage of the absence of normal gravity. To maintain weightlessness or very low gravity, the crew will refrain as much as possible from firing the craft's thrusters for steering or positioning the craft. Changes in spacecraft position or orbital paths cause at least slight disruption of the weightless state. Key research on the mission will include materials-processing and life-sciences experiments.



Retractable Solar Optical Telescope on a Spacelab *pallet inside the Orbiter's cargo bay is planned for a Shuttle flight early in the 1990s.*

Study of Stars Planned

On the first Spacelab *flight—SL-1—the United States and France each has a star and a Sun observation instrument. The Netherlands has a star observation experiment, and Belgium has a Sun observation experiment.*

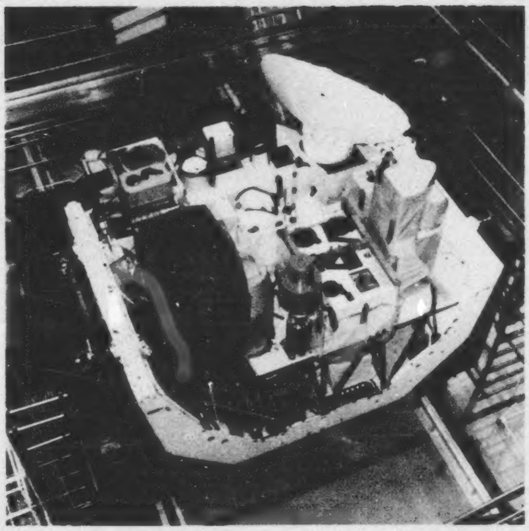
The three star experiments are designed to help scientists study the life cycle of stars from their births through their deaths.

Sky Survey—The French astronomy instrument aboard SL-1 is a Very Wide-Field Camera that the crew uses to take wide-angle ultraviolet-light photographs of vast regions of sky not observable from Earth. Very little large-scale ultraviolet mapping of the sky has been accomplished to date. A payload specialist and a mission specialist install the instrument, a combination telescope camera, into the experiment module's scientific airlock during the flight. Photographs will be used by the Laboratory of Space Astronomy in France for large-scale studies of the structure of the Milky Way galaxy. Astronomers will examine remnants of gigantic explosions that occurred eons ago in the galaxy's center. Ultraviolet radiation is characteristically emitted by very young stars shortly after they form, and by very old stars near the ends of their life cycles.

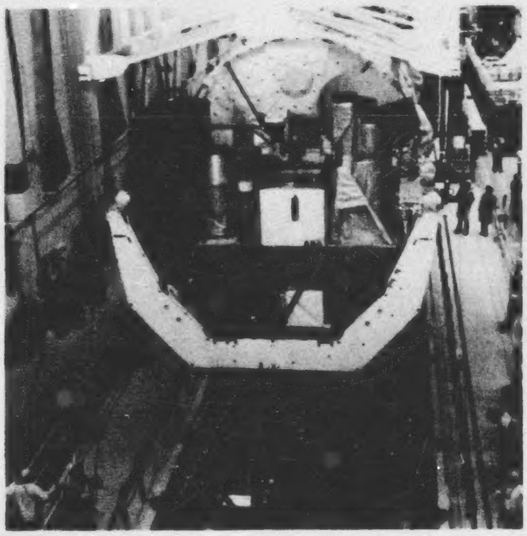
Ultraviolet Telescope—A companion experiment is to be conducted by the United States with an instrument whose major components were built in France. It uses wide-field sensors, more sensitive than ever used before in space, for extensive surveys of very faint sources of ultraviolet radiations. The instrument, called a Far Ultraviolet Space Telescope, has previously been used only for brief rocket observations.

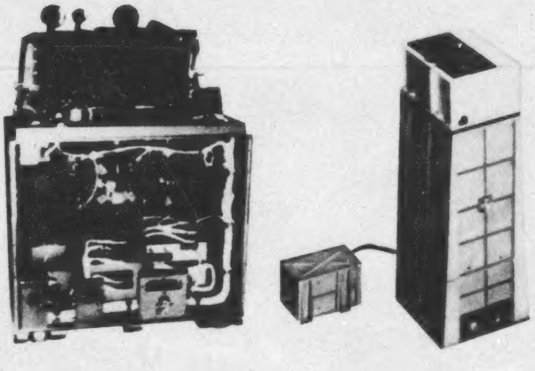
The sensors are sufficiently sensitive to detect the very faint ultraviolet emissions believed to emanate from stars reaching the ends of their lives. The crew will operate this pallet-mounted experiment from controls inside the module. Analysis of the findings will be made by researchers in France and at the University of California, Berkeley, California.

X-ray Detector—An experiment by ESA's European Space Research and Technology Center in the Netherlands detects X rays emitted by stars. X rays originate during violent events in a star's life cycle. The pallet-mounted instrument, controlled from on board and from the ground, contains Xenon gas that responds to bombardment by X rays. As the instrument measures these responses, scientists can determine the strength and



Close-up of a Spacelab-1 *pallet before its installation in the Orbiter's cargo bay shows the variety of instrumentation that can be accommodated by* Spacelab *on a single flight.*





other characteristics of the X rays for clues to evolutionary processes inside the star.

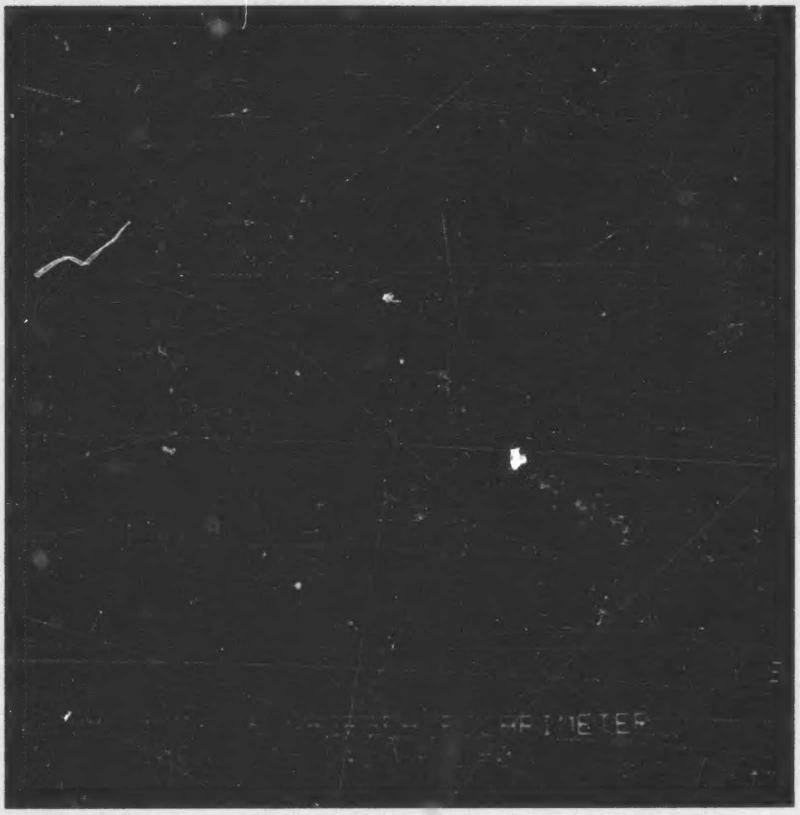
Sun Energy Output to be Measured

Three Sun observation experiments seek to measure the Sun's energy output and its variations. The Sun's radiations are the major influence on our weather.

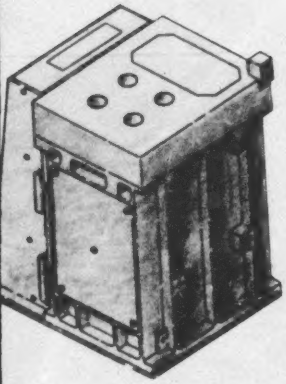
Sun Monitor—An automated pallet-mounted instrument requiring no attention from the crew contains three heat detectors (pyroheliometers). They measure the Sun's radiations, ranging from those in the extreme ultraviolet through those in the far infrared. The instrument, called an Active Cavity Radiometer, is being carried aboard *Spacelab* for scientists at the Jet Propulsion Laboratory in Pasadena, California, who will analyze the measurements.

Energy Detector—This pallet-mounted instrument, called a Solar Spectrum Monochromator, measures three separate kinds of radiations to determine the Sun's energy emissions. Three measuring and counting devices called double monochromators are used—one each for ultraviolet, visible, and infrared radiations—to detect variations in Sun radiations in each radiation range. Changes in each of these ranges have different effects on the atmosphere. Analysis of this experiment's data will be made by the Avionics Service of the National Center for Scientific Research in France. The observations with this instrument and with the radiometer (described above) are the first simultaneously measuring the Sun's total radiations in different spectral ranges from space.

Radiation Sensor—Controlled by the *Spacelab* computer and payload crew, this radiation sensor (pyroheliometer) attempts to measure the solar constant, the total radiation received on the Earth from the Sun, with great accuracy. This measurement also helps determine how much solar radiation is reflected back into space or absorbed by the Earth and helps determine Earth's energy gain, or "radiation budget." The Royal Meteorological Institute in Belgium will analyze the results of this experiment and compare this data with the measurements of the other two Sun observation experiments aboard SL-1—the radiometer and the monochromators described above. All of these three instruments are expected to be reflown repeatedly in space for measurements over long periods of variations in Sun output.



This striking view of the Sun's outer gas envelope—the corona—was prepared from data supplied by a Sun-observing instrument aboard a NASA craft called the Solar Maximum Mission Satellite. *Studies of the Sun's energy output and its influence on the weather and other Earth conditions are among prime research objectives of* Spacelab *flights.*



Three Spacelab *instruments with different sensors will make unprecedentedly precise measurements of various kinds of Sun radiations reaching the Earth. The three instruments are (from left) a* Solar Spectrum *instrument, a* Solar Constant Measurement Device, *and an* Active Cavity Radiometer.

Atmospheric Physics and Earth Observations

Six instruments aboard SL-1 *are designed to study the Earth—four of them the Earth's atmosphere and two the Earth's surface.*

The two surface observation instruments are from West Germany. Three of the atmospheric study instruments are from France and one is from the United States.

Four of these instruments are mounted on the pallet, one is inside the module, and one has components on the pallet and in the module.

Even before the earliest satellites confirmed it, scientists were convinced that a vantage point in orbit would make an ideal observation position for studies of Earth. Its lands, oceans, and atmosphere could be viewed from a new perspective and in ways never before possible.

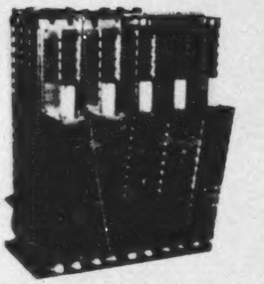
Earlier experience with instruments on balloons, aircraft, and rockets showed they provide only limited information. Their point of view is localized. Sounding rockets which reach altitudes above the atmosphere can look over large areas but their viewing time is very short. Automated Earth observation satellites do provide a sweeping view of vast regions, but the resolution of their observations is usually relatively low because they most often orbit at high altitudes.

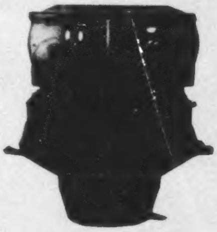
Spacelab, at its relatively low orbital altitude, is expected to combine the sweeping view with high-resolution observations and give scientists the added advantage of crews aboard who can focus and adjust the equipment as they monitor it for best possible results.

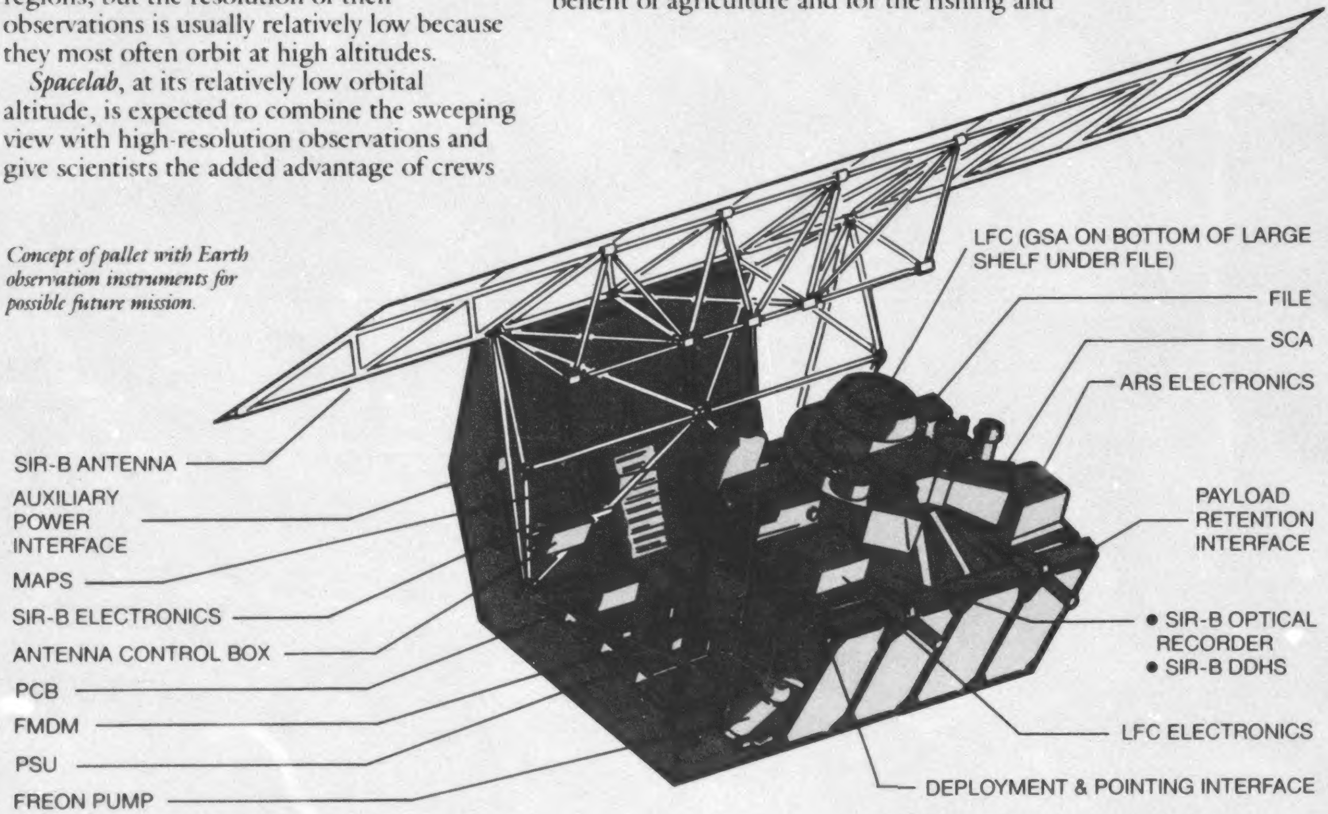
Six Experiments Study Earth

Metric Camera—Only a little more than one-third of the Earth's land areas have been mapped adequately for the global resources planning required to accommodate the planet's rapidly increasing population. Conventional techniques are too slow to provide the needed up-to-date maps. SL-1 carries a metric camera similar to those used in surveys from airplanes. In-orbit tests will determine whether the camera can be used from space to map the remaining two-thirds of Earth's lands within a short time. The camera, which is being included for experimenters in West Germany, uses 24-centimeter (10-inch) film to provide photographs with much better resolution than is obtained from most unmanned, automated Earth-observation satellites. The crew mounts the camera in the core module's viewport. The camera is controlled by the *Spacelab* computer and the payload crew.

Microwave Sensor—Uninterrupted monitoring of Earth conditions for the benefit of agriculture and for the fishing and



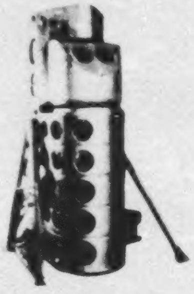



LFC (GSA ON BOTTOM OF LARGE SHELF UNDER FILE)
FILE
SCA
ARS ELECTRONICS
PAYLOAD RETENTION INTERFACE
• SIR-B OPTICAL RECORDER
• SIR-B DDHS
LFC ELECTRONICS
DEPLOYMENT & POINTING INTERFACE
SIR-B ANTENNA
AUXILIARY POWER INTERFACE
MAPS
SIR-B ELECTRONICS
ANTENNA CONTROL BOX
PCB
FMDM
PSU
FREON PUMP

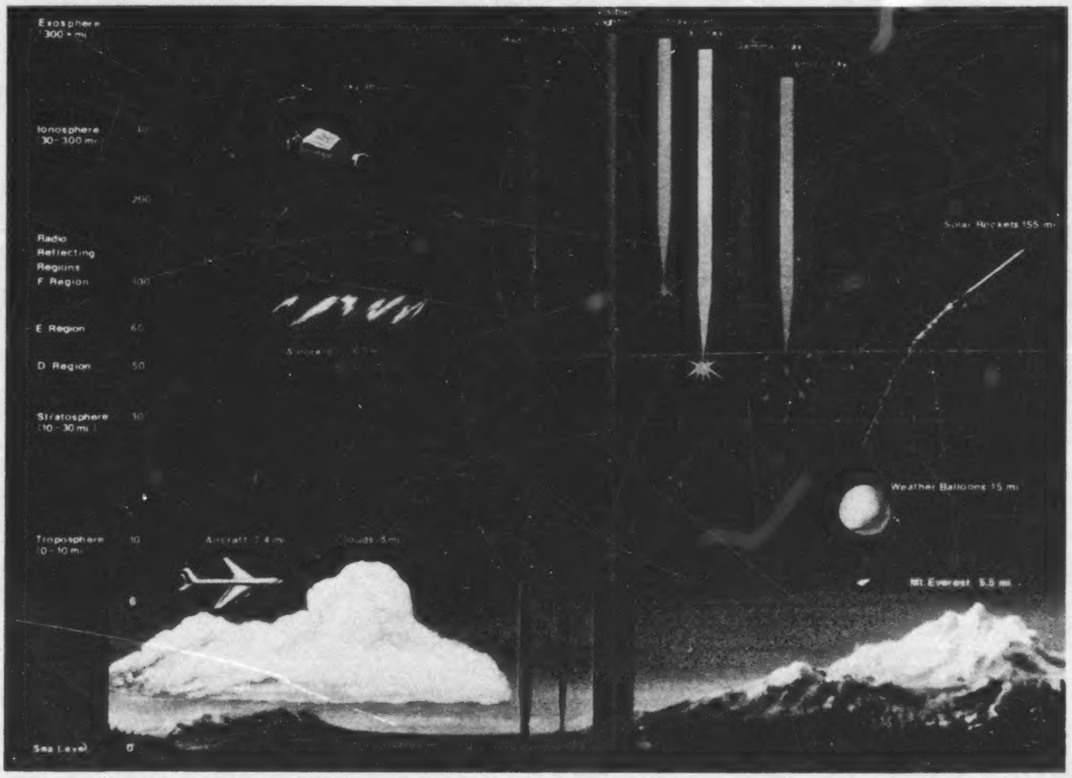
Concept of pallet with Earth observation instruments for possible future mission.

transportation industries can be obtained through microwave sensing from orbit. To develop such a system for a planned European satellite that can "see" land and ocean surfaces through clouds and under all weather conditions, a microwave radar facility is being flown on SL-1 for scientific investigators in West Germany. The facility's antenna is mounted on the pallet, but the instrument's other components are in the module. The instrument is operated automatically. Data processed by the on-board computer is transmitted to the ground for analysis.

Atmospheric Studies—A 16-mm movie camera on board SL-1 will take some 2,000 photographs to learn about the origin and behavior of cloudlike phenomena which have been observed in the atmosphere at altitudes of about 85 kilometers (53 miles). The camera is part of a French experiment called Waves in the OH Emissive Layer for studies of the atmosphere from orbit. Another French instrument called the Grille Spectrometer is designed to study the presence of carbon dioxide, water vapor, ozone, and other gases in the atmosphere at altitudes between 15 and 150 kilometers (9 to 93 miles). Still another French experiment measures radiation resulting from action of sunlight on hydrogen in the Earth's atmosphere, in the solar system, and in our galaxy. A U.S. experiment in the SL-1 atmospheric series, contributed by scientists at the Utah State University, measures airglow in the atmosphere in visible and invisible light. From these observations scientists can determine chemical processes in the atmosphere and its composition. All of the atmospheric experiments are mounted on the pallet.



A high-resolution metric camera (shown at lower left) and an all-weather microwave remote sensing system (near right) that can see through clouds for monitoring crops, oceans, and other Earth conditions, make up the Earth observation experiments aboard the first Spacelab *flight. Four other instruments on the mission, which study the atmosphere, are an* Imaging Spectrometric Observatory *(top left) a Lyman emission detector (center top) a detector for cloudlike structures in the upper atmosphere (bottom center) and a Grille spectrometer (far right).*



Of the immense quantities of radiation that pervade the Universe and impinge on the Earth, only those in visible light and radio and a few in infrared are able to penetrate to the Earth's surface. Spacelab*'s position above the atmosphere permits observation of all radiations, including those screened out by the atmosphere.*

“Spacelab *is the first project that European industry undertook in the manned space flight field. . . . I consider that we have learned a great deal in the technical as well as in the management field. With American support, from* NASA *and the American industrial companies, we have today acquired a competence in this field which enables us to approach more complex projects in manned space flight in the future. . . .”*

Michael Bignier, Director, Space Transportation Systems, ESA, November 28, 1980, at the completion of the engineering model of *Spacelab* in Bremen, West Germany.

CHAPTER 6

A Day Aboard Spacelab

A clash of cymbals, a thunderous roll of drums, then a flourish of trumpets, and the band breaks into a rollicking tune.

The blaring music from the Mission Control Center in Houston pervades the Orbiter's mid deck and jolts three crew members from their sleep to sudden consciousness.

Each of them stretches—but in weightlessness the feeling is not the same as on the Earth, where we push against the pull of gravity.

They open their eyes and at once each of them remembers that this is not a day on Earth but a Shuttle-*Spacelab* mission, and there is no time to linger.

Left to right, in this photograph inside the Spacelab-1 *module, are Payload Specialist Ulf Merbold, Payload Specialist Alternate Michael L. Lampton, Payload Specialist Bryon K. Lichtenberg, and Mission Specialist Owen Garriott. The four conducted performance tests in April 1983 while the module was inside the Operations and Checkout Building at Kennedy Space Center, Florida.*

Day in Orbit Begins

A *Spacelab* shift change is about due. The three—the pilot, a mission specialist, and a payload specialist—make up the "Blue Shift." They start at once to prepare themselves to exchange places with the three other crew members—the commander, the other mission specialist and the other payload specialist—who are designated the "Red Shift."* The Red Shift is nearing the end of a 12-hour duty period at their work stations on the Orbiter's flight deck and in the *Spacelab* module.

This is the beginning of another day for the Blue Shift and the approach of the end of the day for the Red Shift.

Recorded music from mission control has been the traditional wake-up call used by NASA for space crews for more than 20 years, ever since Astronaut L. Gordon Cooper, Jr., became the first American to sleep in space in mid-May 1963. Cooper's 34-hour, 22-orbit mission was the first U.S. manned overnight flight in space and the last in the six-flight series with the one-man Mercury spacecraft. Alone in that small craft, Cooper could not stand or stretch, but had to sit cramped on that craft's small seat throughout the flight whether awake or asleep.

In comparison to Mercury, living quarters for Shuttle-*Spacelab* crews are almost luxurious.

Shuttle-*Spacelab* crew members can recline on three comfortable bunks built into the starboard wall of the living quarters in the Orbiter's mid deck on the lower level of the two-tiered crew compartment. That

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**On the SL-1 flight the Red Shift is made up of crew members Young, Parker, and Merbold; the Blue Shift, Shaw, Garriott, and Lichtenberg.*

compartment is forward, just behind the craft's nose. The upper level, called the flight deck, holds instrument and control panels for the commander and pilot and also includes work stations with controls and displays for the mission and payload specialists. The display and controls resemble a large airplane's cockpit.

Equipment for each bunk includes pillows and individual light, fan, communications station, sound-suppressing blanket, and sheets with restraints to keep the sleeper from drifting off weightlessly through the cabin.

Sleeping in Weightlessness

On the first several Shuttle flights crew members still used cocoonlike sleeping bags attached to the provision lockers and somewhat resembling the sleep stations of *Skylab.* The Orbiter retains one such station near the bunks. Crew members enter a small closetlike enclosure, hook themselves up, and go to sleep in an apparently vertical position. Since there is no up or down in weightlessness, the sleeping orientation is of no concern.

Feeling rested and alert, the three Blue Shift crew members unclasp the restraints and are about to plunge into their morning routine when a voice from mission control on their speaker comes up with another U.S. space tradition—an early-morning news summary from Planet Earth: A professional baseball team dropped an important game, to the disgust of the fans in the crew. One of the crew members' children won a prize in a collegiate contest. The voice at mission control thought the father would like to know. The European crew member hears the results of an international soccer match. The President held a news conference in which he said the nation is eagerly watching *Spacelab*'s progress. It has been raining in Houston almost continuously ever since the flight began. But long-range forecasts indicate ideal conditions at the Kennedy Space Center in Florida a week hence, when the Orbiter returns there for its landing on the oversize three-mile runway. Otherwise, the voice says, our Earth is still spinning as it always has.

Lavatory in Orbit

The Orbiter has only one washroom and toilet. Crew members take turns—like a traveling family sharing a motel room. Sanitation facilities are much the same as on the Earth. Airflow substitutes for gravity in carrying away the wastes.

Plastic sleeves around the hand wash basin keep stray droplets from floating away into the cabin. Streams of air rush water over the hands and then out into the wastewater collection tanks. Floating water droplets in the cabin would become a nuisance, as well as a hazard to equipment and crew.

Toilet waste is pushed by air streams into a container. Some waste may be intentionally saved. Its analysis tells doctors which minerals crew members may lose excessively in weightlessness. Such periodic checks increase the understanding of bodily functions and indicate what food supplements may be needed for space travelers on lengthy flights in the future.

Crew members may use conventional shaving cream and safety razors and disposable towels. For those preferring electric shavers, there is a windup shaver operating like an electric model but requiring no plug or battery. It has a built-in vacuum device that sucks up whiskers as the shaving proceeds. Free-floating whiskers could foul up equipment and become a serious nuisance. For a sponge-bath, the only kind available, there is a watergun adjustable for temperatures from 18 to 35 degrees C (65 to 95 degrees F).

Preparing a Space Shuttle meal inside the engineering model at the Johnson Space Center in Texas are Scientist-Astronaut Dr. Rhea Seddon (right) and Astronaut Donald E. Williams. Williams is rehydrating food in a package with a water dispenser also known as a water gun. Dr. Seddon is preparing a beverage package for rehydration. Food trays are shown attached to locker doors. Utensils are attached to trays with Velcro tabs. The model resembles the galley on the mid deck of the Orbiter's crew compartment.

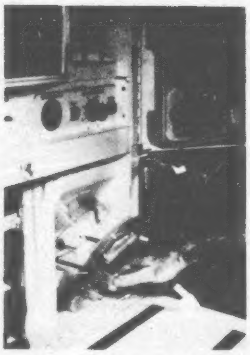
Variety in Space Menus

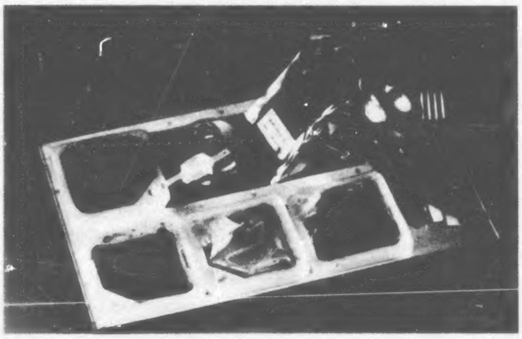
For breakfast the Blue Shift enjoys orange drink, peaches, scrambled eggs, sausages, cocoa, and sweet rolls. The food as well as the food preparation facilities could easily be the envy of many earthbound chefs, homemakers, and diners. Crew members can select from a menu almost as varied and certainly as tasty and nutritious as in most homes or restaurants. One crew member can prepare meals for his shift in about five minutes. Members of the Blue and Red Shifts may eat breakfast and dinner together on some missions if schedules permit.

In a galley to the left of the bunks are an oven, hot and cold water dispensers, and a pantry stocked with 74 kinds of food and 20 different beverages. There are drinking cups and eating utensils. Dining trays separate different food containers and keep them from lifting off and floating through the cabin.

There is no refrigerator and none is needed. To save weight and space, most on-board foods are dehydrated by a freeze-drying process developed specially for space use. Ample water for reconstituting these foods is provided by the fuel cells, which deliver clean water as a by-product of their electricity-generating chemical processes.

Some foods are stored in conventional sealed, heat-sterilized cans or plastic pouches. A few foods, such as cookies and nuts, are in ready-to-eat form. Meals provide for an average of 2,700 calories daily. Experience from earlier space flights shows crews need about as many calories in space as they do on Earth.





Rehydration unit for use in meal preparation in the galley aboard the Shuttle's mid deck. Part of a new six-compartment food tray is seen at upper right. Spacelab *has only work facilities and no living quarters. The crew returns to the Orbiter's mid deck to eat, sleep, relax, and use sanitary facilities.*

A typical lunch: cream-of-mushroom soup, ham-and-cheese sandwiches, stewed tomatoes, banana, and cookies; a typical dinner: shrimp cocktail, beefsteak, broccoli au gratin, strawberries, pudding, and cocoa.

There is no washing machine. Garbage, trash, and soiled clothing are sealed in airtight plastic bags. This is an important health measure, because studies have shown that microbes can increase in extraordinary quantities in a confined, weightless environment.

Shift Change Described

The Blue Shift is ready for the day's work. The pilot floats through the open hatch leading through the mid deck's ceiling. He emerges through the floor of the flight deck on the cabin's upper level and takes his seat to the right of the commander. Both are on identical seats, facing the instrument panels. Both are on duty during launch, de-orbit, and reentry, as well as during other critical space maneuvers. The consoles in front and to their sides have duplicate flight controls to enable them to operate the Orbiter from each seat independently should an emergency require it. During launch and reentry one or two mission specialists sit on removable seats behind them. Remaining mission specialists and the payload specialists sit below on the mid deck.

The commander now briefs the pilot on the Orbiter's performance during the last 12 hours. Then the commander signs off with mission control, leaving the pilot in charge. He lowers himself through the hatch into the mid-deck living quarters to begin his 12-hour recreation and sleep period.

In the aft flight deck, directly behind the pilot but facing to the rear of the cabin, the Blue Shift mission specialist has taken his place at the mission operation display and controls and scrutinizes the video display indicating the performance of Orbiter-*Spacelab* systems, including electrical power and communications supporting *Spacelab*. Two windows, both to his right in the back wall of the flight deck, look out on *Spacelab* in the cargo bay.

The Blue Shift mission specialist confers on the intercom with his Red Shift counterpart who is presently inside the module working with the payload specialist on experiments. Having satisfied himself that readings are normal, the Blue Shift mission specialist moves down through one of the flight deck floor hatches to the mid deck, then into the tunnel to the module. There he takes the place of the Red Shift mission specialist, who returns through the tunnel to the mid-deck living quarters for his recreation and sleep period.

The Blue Shift payload specialist takes the route followed by the mission specialist into the module. There, after receiving a short briefing about events in the last 12 hours, he takes the place of the Red Shift payload specialist, who leaves the module for his rest period in the living quarters.

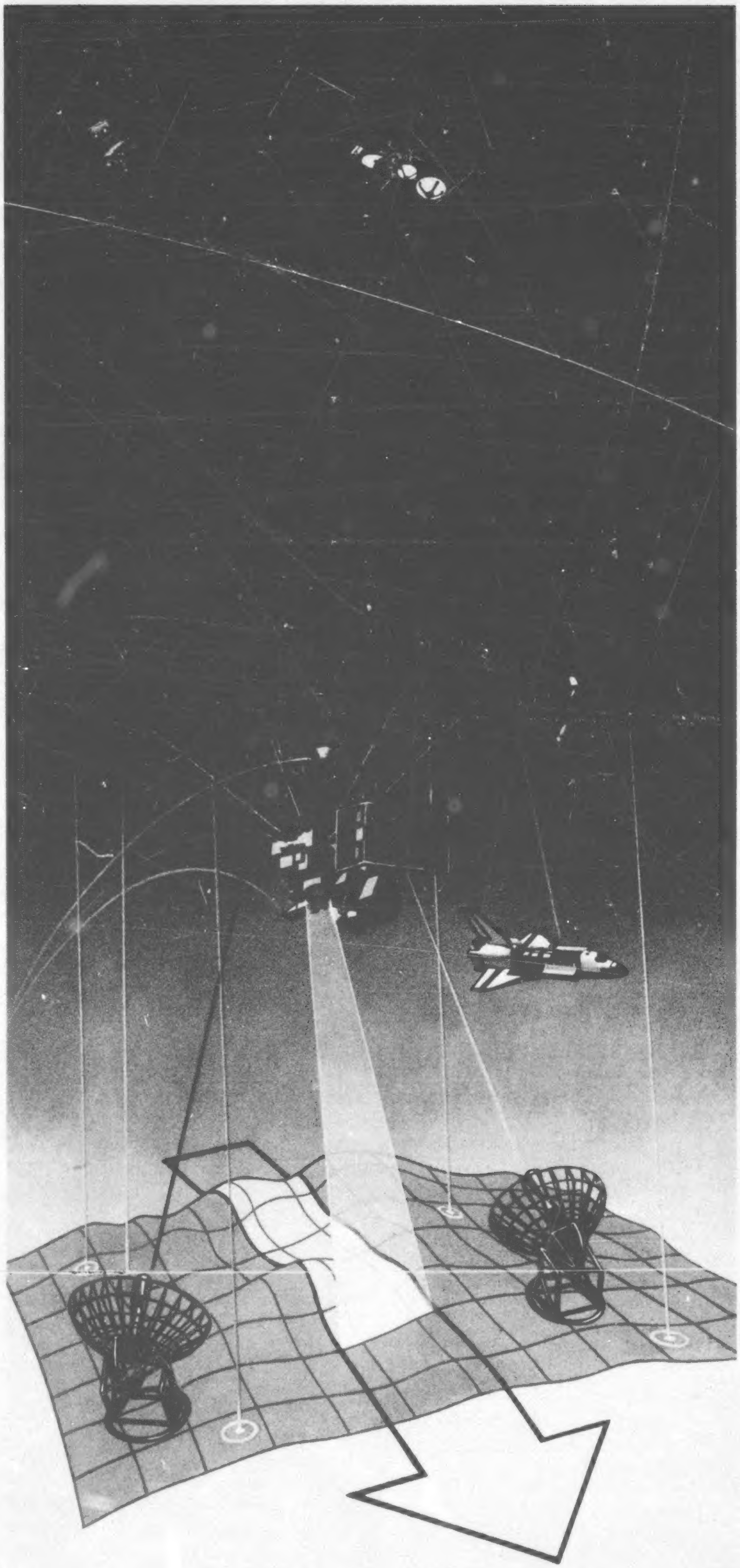
Having begun their work, the Blue Shift mission specialist and payload specialist inside the module discuss upcoming experiments with experts on the ground. It is a new experience in manned orbital flight. Long, continuous space-to-ground-to-space communications have not occurred since the Apollo Moon flights. In those the long distance of the craft from the Earth gave the crews a sweeping view of Earth, so that at least one of the deep-space antennas on three continents were in communication with the spacecraft at all times. But the relatively low orbital altitudes of all other manned flights leave ground-based antennas beyond the spacecraft's horizon during most of each orbit. Rarely more than about 20 minutes of communication time was available during each 90-minute orbit.

Communications Via Satellite

Though not yet in full operation for SL-1, a new communication facility called the Tracking and Data Relay Satellite System (TDRSS) will eventually provide coverage a large part of the time for *Spacelab* and all other Shuttle flights wherever they are in Earth orbit.

When completed, TDRSS (NASA officials pronounce the acronym "tea dress") is to consist of three stationary (Earth-synchronous) communications satellites. Two of these are to be in operation, while the third is to be in orbit as a spare to replace any malfunctioning satellite.

At the altitude of 35,890 kilometers (22,350 miles)—some 150 times higher than the Orbiter—at least one of the two operating TDRSS satellites is nearly always in the line of sight with the Orbiter. Both satellites will always be in view of the TDRSS ground station at White Sands, New Mexico. The two operating satellites act as relay stations for the Earth-to-TDRSS-to-Orbiter-*Spacelab*-to-TDRSS-to-Earth communications. Voice, video, and data between the White Sands station and the control center at the



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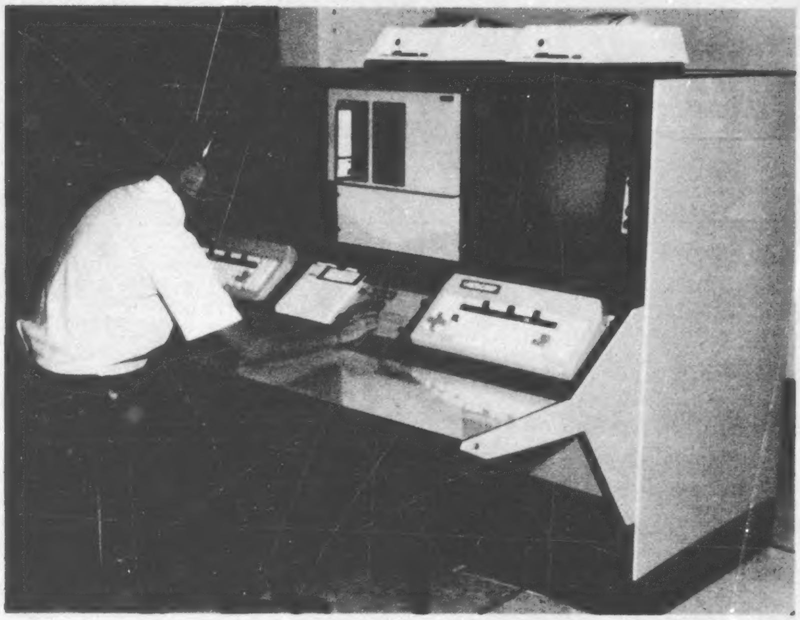


Scientists on Earth can monitor and participate in Spacelab *experiments almost as if they were aboard the Orbiter through communications links which give them the same instantaneous instrument and computer readouts and displays at the Payload Operations Control Center (POCC) (shown here in simulation) in Houston, Texas.*

Johnson Space Center are transmitted via domestic communications satellites.

TDRSS, expected ultimately to replace most of the ground stations of NASA's 20-year-old Spaceflight Tracking and Data Network, has only one of its satellites in orbit in time for use during the SL-1 mission. That satellite (TDRS-A) was launched April 5, 1983, from the cargo bay of the Orbiter *Challenger*, then making its maiden flight. It was the sixth Shuttle flight (STS-6). After a malfunction in an upper stage rocket the satellite entered an elliptical orbit far too low to serve its intended communications function. By a series of carefully calculated firings of the satellite's small thruster engines by remote radio command, NASA and industry controllers gradually raised that orbit over a period of several weeks to a circular orbit at synchronous altitude. The launch of the second TDRSS satellite (TDRS-B), has been postponed to 1984.

To compensate partly for the curtailment of transmission capabilities before the availability of TDRS-B, SL-1 carries more recording tapes than had originally been planned for storing research instrument data on board during communications interruptions, until they can be transmitted to Earth or returned with *Spacelab*.

TDRSS's planned capacity for voice, data, and video communications between ground stations and orbiting satellites is expected to introduce a new dimension to manned-space science activities. This capacity will be exploited for the first time with *Spacelab*. Scientists on the ground can watch their own experiments as they are being operated aboard *Spacelab*. When the TDRSS is fully operational, they will be able to see experiment results on video screens and computer readouts on the ground at the same time as the payload specialists who are conducting the experiment in *Spacelab*. Earthbound scientists can discuss an experiment with the payload specialists as the experiment progresses in *Spacelab*.

*(Opposite) NASA's new Tracking and Data Relay Satellite (TDRS), top right, serves as an orbit-to-ground-to-orbit communications link for Shuttle/*Spacelab*, far below at right, as well as for other low-altitude satellites such as the Landsat Earth observation satellite, center. Another high-altitude communications satellite, top left, acts as a relay between the TDRSS' ground stations (antennas at bottom). The four-satellite Global Positioning System is shown in red. The U.S. Space Telescope, right center, to be launched in 1985, is shown also using the TDRSS.*

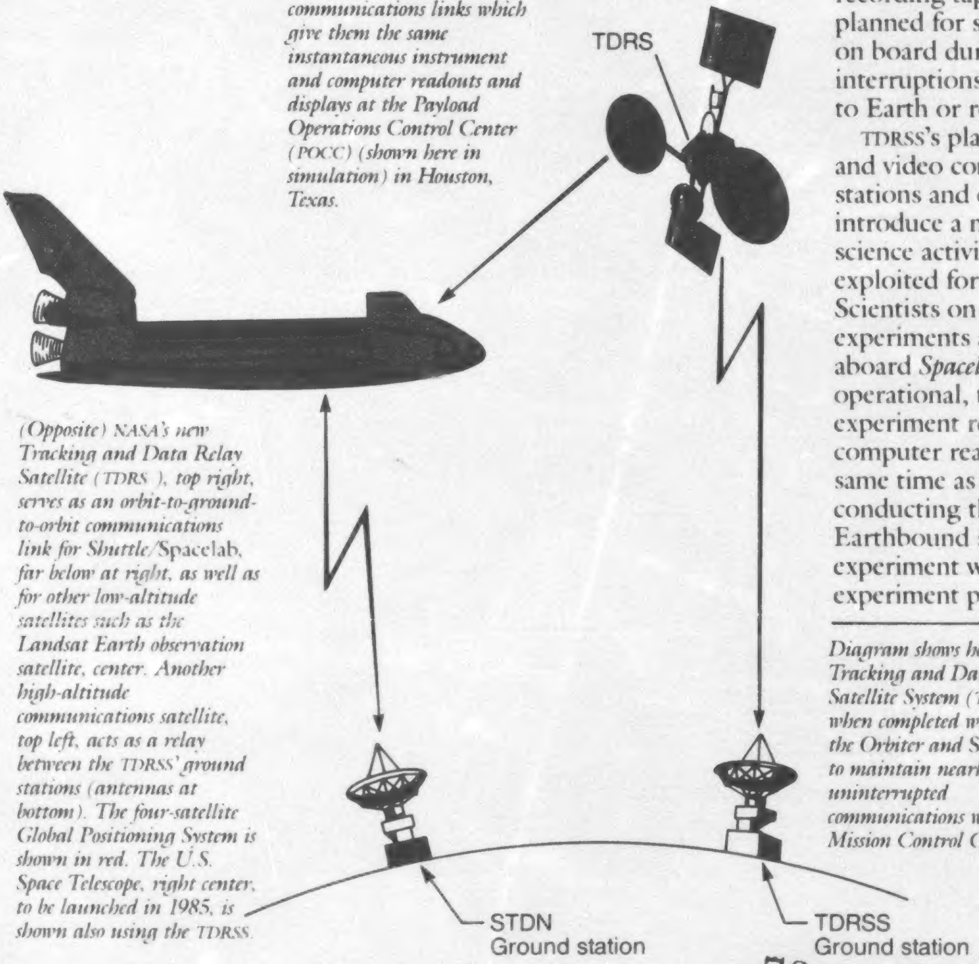


Diagram shows how the new Tracking and Data Relay Satellite System (TDRSS) when completed will allow the Orbiter and Spacelab *to maintain nearly uninterrupted communications with the Mission Control Center in Houston during orbital flights. Only one of the satellites was in operation in time for the first* Spacelab *flight. In earlier orbital flights crews could usually communicate with ground stations for only about 20 percent or less of each orbit.*

To make this new kind of interactive Earth-to-orbit-to-Earth collaboration possible, NASA has established a Payload Operations Control Center (POCC)—pronounced "pock." It is located in the Mission Control Center Building at the Johnson Space Center in Houston. Scientists from around the world whose experiments are carried aboard *Spacelab* gather at the POCC and use its voice, video, and data communications facilities for live observations of ongoing *Spacelab* experiments and to hold remote conferences with the crew operating their experiments. Eventually scientists will be able to participate in mission operations from their own laboratories in universities and research centers around the world, where they would instantaneously receive the same instrument readouts as their payload specialist colleagues aboard *Spacelab*.

Earthbound scientists can point out unforeseen research opportunities which may be developing unexpectedly as an experiment progresses. They can advise the payload specialist how best to take advantage of them—or how to deal with unexpected problems.

Spacelab Interfaces with Earth

How well this can work has been vividly demonstrated during numerous POCC simulation exercises. In a simulation that could become real on the SL-2 astronomy mission, this conversation was typical:

"I'm looking at a filament [a streamer from a spot on the Sun]," said a scientist while watching a simulated transmission at a POCC TV monitor. Addressing himself to the payload specialist aboard the Spacelab *training unit, he suggested, "Is there a thinner filament somewhere?" "OK," replied the payload specialist, "I'll move [the telescope] to another edge. Is this better?" "Great," replied the scientist. "Just what I want. Great!"*

Though such scientist-astronaut collaboration was successfully carried out on several earlier U.S. space flights, particularly during geological field trips by astronauts on the Moon's surface in Apollo missions, these efforts were severely hindered by the short communications periods available on Earth-orbital missions and by the crews' operational duties. For example, crews on Moon walks had to watch and regularly report on the function of their life support systems and orbital crews had to monitor and report frequently on the status of their craft's vital systems. Time available for science exchanges was very limited.

In contrast, payload specialists aboard *Spacelab* can devote almost their entire attention and time to the scientific experiments.

As on every manned U.S. space flight, crew activities aboard *Spacelab* are governed by a flight plan. Known as a "timeline," this program schedule spells out minute by minute in around-the-clock listings the time and order of every event aboard *Spacelab* and what each crew member is expected to be doing at any particular time during the mission. *Spacelab* timelines show exactly when each research instrument is to be turned on and off, when readings need to be taken, and when other observations are to be made.

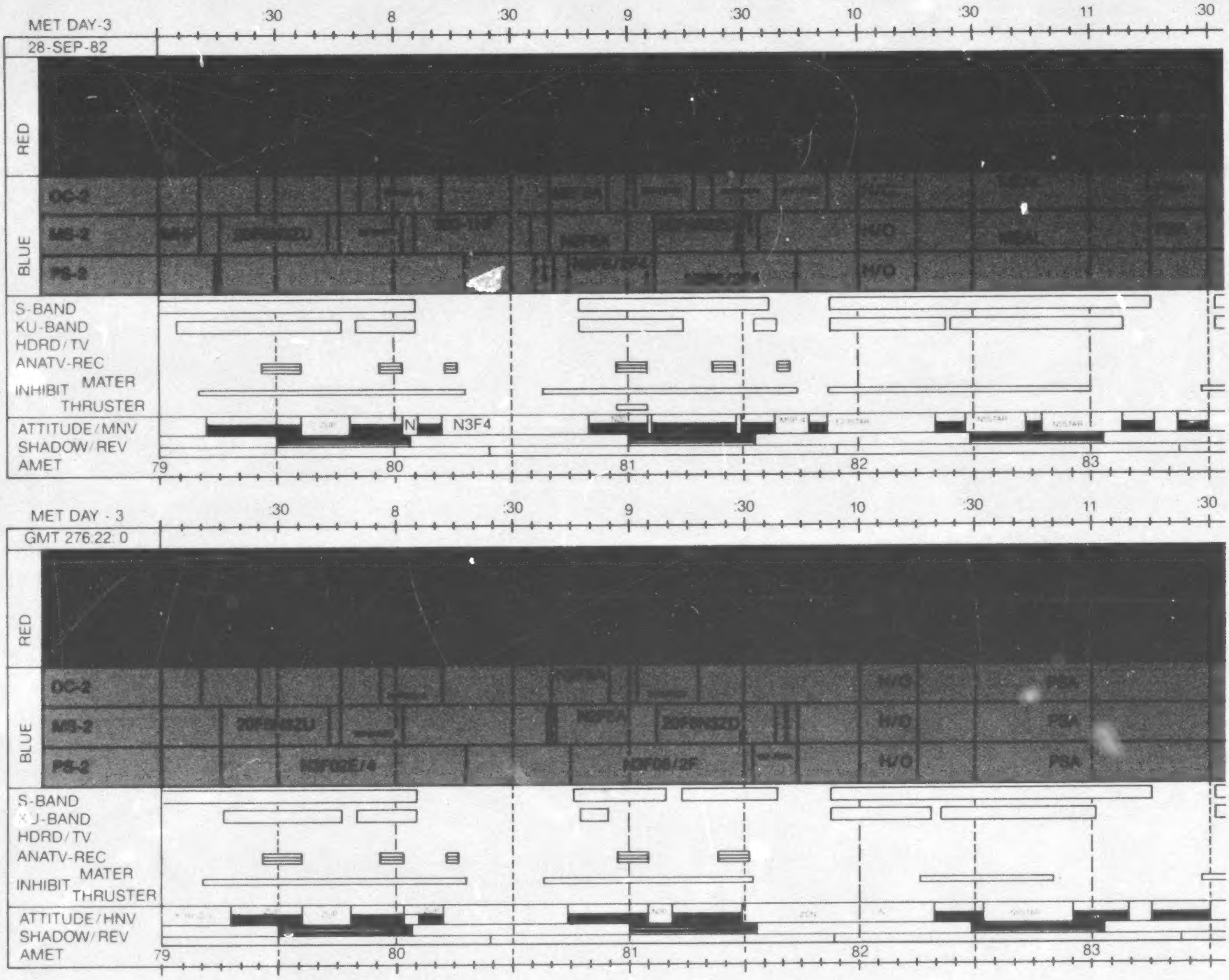
Experience shows that, particularly when a new craft or new instrument is first flown, unexpected problems or malfunctions sometimes force timeline changes during the flight. Similarly, if in the judgment of the crew, the scientists, and mission controllers unanticipated favorable conditions hold out the promise of extraordinary research gains, on-the-spot timeline changes can be made to take advantage of this serendipity.

Spacelab timelines are the culmination of preparations and planning which began before the flights, years ago. These preparations began with the selection of experiments from hundreds of proposals submitted by scientists from many nations. Committees of scientists screen the proposals and choose those that appear to promise the most significant research results. Obviously, only experiments suitable for *Spacelab* are chosen. Weight, size, power consumption, and requirements for computer and crew time are carefully evaluated.

Working Group Provides Help

The Investigators Working Group for a particular mission, including the principal investigators associated with the experiments, helps the mission manager make decisions regarding experiments.

Is a proposed lengthy experiment taking away too much orbital observation time from other experiments that require the Orbiter to



Pages from SL-1 timeline.

be positioned in a different direction? Can a proposed Sun observation experiment obtain sufficient data without causing overheating of Orbiter parts exposed to the Sun for a long period? Will Orbiter parts become excessively cold from facing away from the Sun for a long time while accommodating an astronomy experiment?

Is there enough electrical power available for *Spacelab* to run proposed simultaneous experiments? If not, how can experiments be curtailed? Would elimination of a sample from a materials science experiment and the taking of fewer photographs in another experiment keep electricity requirements within the power budget? What are the trade-offs?

After an experiment has been designed and its equipment constructed and tested, it is shipped by the researchers to Kennedy Space Center's Operations and Checkout (O&C) Building. About as long as a football field and nearly as wide, and 50 feet (15 meters) high, the O&C Building comprises a virtual assembly line for space science. It has facilities where arriving experiments are unpacked, retested by the experimenters themselves, and readjusted and recalibrated before they are installed on the pallets or in the racks. Additional testing assures that the research instruments can share *Spacelab* accommodations without interfering with each other or with *Spacelab* or Orbiter systems.

Loaded racks are then connected with each other into rack trains in the same sequence in which they are to appear in the module and are lifted inside it.

Modules and pallets are then transferred to the Orbiter Processing Facility and there installed in the Orbiter's cargo bay. The Orbiter, with *Spacelab* aboard, is moved to the Vehicle Assembly Building where the Orbiter is mated to the large external fuel tank and two solid rocket boosters. Then the entire assembly is moved on the tractor crawler to the launch pad and readied for liftoff.

Payload Specialists Get Training

Meanwhile, mission and payload specialists are undergoing intensive training, much of it in simulators—replicas that behave as closely as possible to flight units.

This picture of a crew member at work at a data systems display terminal inside Spacelab *will repeat itself often in orbit. Here at the* Spacelab *Payload Crew Training Complex at NASA's Marshall Space Flight Center in Huntsville, Alabama, Dr. Claude Nicollier shows what the terminal will look like. Dr. Nicollier, a Swiss astronomer, was one of the original five payload-specialist candidates for* Spacelab-1. *He is presently in training as a Mission Specialist at the Johnson Space Center in Houston, Texas.*

In Johnson Space Center's Orbiter simulator, payload specialists acquaint themselves with the layout and furnishings of the Orbiter's living and work areas and practice using these facilities. Since *Spacelab* has no living facilities other than its laboratory-workshop, crew members have to commute through the tunnel to the Orbiter's mid deck for food, recreation, sleep, and the use of sanitary facilities.

At JSC's *Spacelab* simulator the mission and payload specialists learn how to use the *Spacelab* systems such as the Control and Data Management System and the scientific airlock. At Marshall Space Flight Center's Payload Crew Training Complex they rehearse their timeline schedules. In training sessions running continuously for many hours they simulate operating the research instruments as scheduled. Computers programmed to simulate each instrument's responses to the crew's inputs make these training sessions almost indistinguishable from their experiences later on the flight.

The computers are programmed to simulate problems and malfunctions of the instruments as part of payload specialists' training for handling almost any contingency.

For past space flights this type of training has been so realistic that returning crews have said the mission itself seemed to be merely another simulation. Sometimes the flights seemed easier than the simulations filled with the computer-contrived problems and malfunctions. Fortunately, most of these contrived emergencies never occurred during the flights.

Much of the training of payload specialists takes place at the laboratories of the chief investigators who designed the experiments. Payload specialists spend much of their time traveling to these laboratories and meeting with these scientists and their staffs. Frequently the mission specialists accompany them on these trips. They learn operation of the instruments and their idiosyncracies—how to use them, adjust them, and repair them.

The trip in space may be a one-time experience for many payload specialists. Their attention will be deeply absorbed in almost nonstop explorations into the unknown. There are unlikely to be any ordinary days for them aboard *Spacelab*, if indeed any day that has 15 sunrises and sunsets can ever be called ordinary. As they complete each of their 12-hour duty shifts, they will almost certainly have had a day as exciting and satisfying as any scientists ever had at their work.

Two Shifts an Innovation

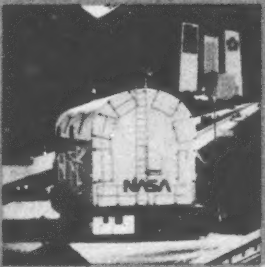
STS-9/SL-1, which is America's 40th manned space flight, is the first with regular in-flight shift changes. On all except a few earlier U.S. manned space flights, all crew members worked and slept at the same hours. While they were asleep, mission control watched the spacecraft systems remotely via telemetry. Built-in alarm systems awakened the crew in emergencies.

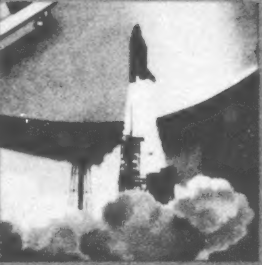
Though there are obvious advantages in keeping experiments operating and under direct observation on a 24-hour-a-day basis, some observers believe the schedule of two 12-hour shifts will not become a permanent feature of U.S. space missions. They reason that, in a relatively small spacecraft, off-duty crew members are likely to have their sleep disturbed by noise from the working members of the crew and operating instruments. Single shifts for the entire crew are planned for some *Spacelab* flights.

As the Red Shift crew members begin their recreation period on the mid deck, one of the three may dictate the recollections of the day's happenings into a tape recorder and make some written notes for a private diary. Others may relax with a variety of games stocked for their use during leisure hours. Music for after-dinner listening is available from the mid deck's small tape library before they sleep. In a few hours mission control will again jar them awake with the blaring notes of the next wake-up call.

*"S**hakespeare once wrote: 'Thoughts are but dreams 'til their effects be tried.' With* Spacelab *we have transformed the thoughts and dreams of thousands into reality."*

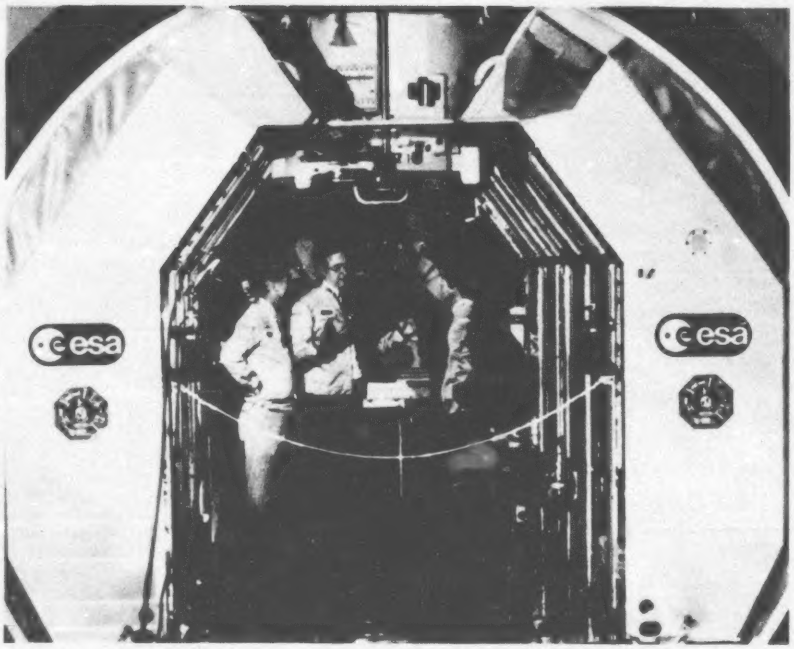
James M. Beggs, NASA Administrator, at the ceremony for *Spacelab's* arrival from Europe at the Kennedy Space Center in Florida, February 5, 1982.





CHAPTER 7

Spacelab: Its Birth, Its Impact, Its Future



Inside Spacelab *Vice President George Bush (center) talks with two crew members—Mission Specialist Dr. Owen K. Garriott (left) and Payload Specialist Dr. Ulf Merbold. Photo was made in the Operations and Checkout Building at the Kennedy Space Center in Florida shortly after the flight model of* Spacelab *arrived there in February 1982.*

The basic decisions were made early in the 1970s. Now, more than 10 years later, when the familiar countdown at the Kennedy Space Center culminates in liftoff, *Spacelab* is finally on its way to orbit aboard the Shuttle. The thoughts that were but dreams a decade ago will be ready for "their effects [to] be tried."

Spacelab's work is not as dramatic or spectacular as the Moon flights were. Yet together the Shuttle and *Spacelab* comprise the foundation for the U.S. manned space programs for the remainder of the 1980s and very likely deep into the 1990s.

Experience from Shuttle and *Spacelab* operations and research is bound to influence the design, direction, and extent of future space projects, particularly of manned space activities, for the next decade or two. Moreover, the success of *Spacelab*'s performance and the research carried out on board will undoubtedly have a significant impact on future international cooperation in space ventures.

The first seeds of the *Spacelab* concept were sown in the late 1960s. Dr. Thomas O. Paine, then NASA Administrator, traveled to 19 countries to assess their interest in cooperating with the United States in space. The first U.S. Apollo manned Moon landings were high priority aspects of the American space effort. U.S. space planners were looking at possibilities for post-Apollo programs. They were appraising projects to succeed the manned Moon landing missions.

All Apollo follow-on programs seriously considered were necessarily expensive. Most of them implied worldwide efforts. Thus they were candidates for international sharing.

Task Group Considers Options

Evolution of the *Spacelab* concept had its beginnings in a task group appointed during the Nixon Administration. With the work on the Apollo series of spacecraft completed, personnel were directed to investigate how NASA might best conduct scientific investigations in space during the closing decades of the 1900s.

Options they considered included (a) a reusable Space Shuttle vehicle; (b) a manned planetary expedition to Mars; and (c) design and construction of a permanent orbiting space station.

President Nixon decided that only one of these options at a time would be supported. Space Shuttle was the one chosen.

Supporting studies for the post-Apollo effort in space had focused on modular space stations, assembled in orbit from units of a sufficiently small size for delivery in the Shuttle's cargo bay. In their discussions of a space station, engineers often referred to "research and applications modules" (RAMS). These unmanned units would be designed to carry research instruments into orbit, stay for a year or two, and then be returned to Earth and exchanged for other units with new experiments.

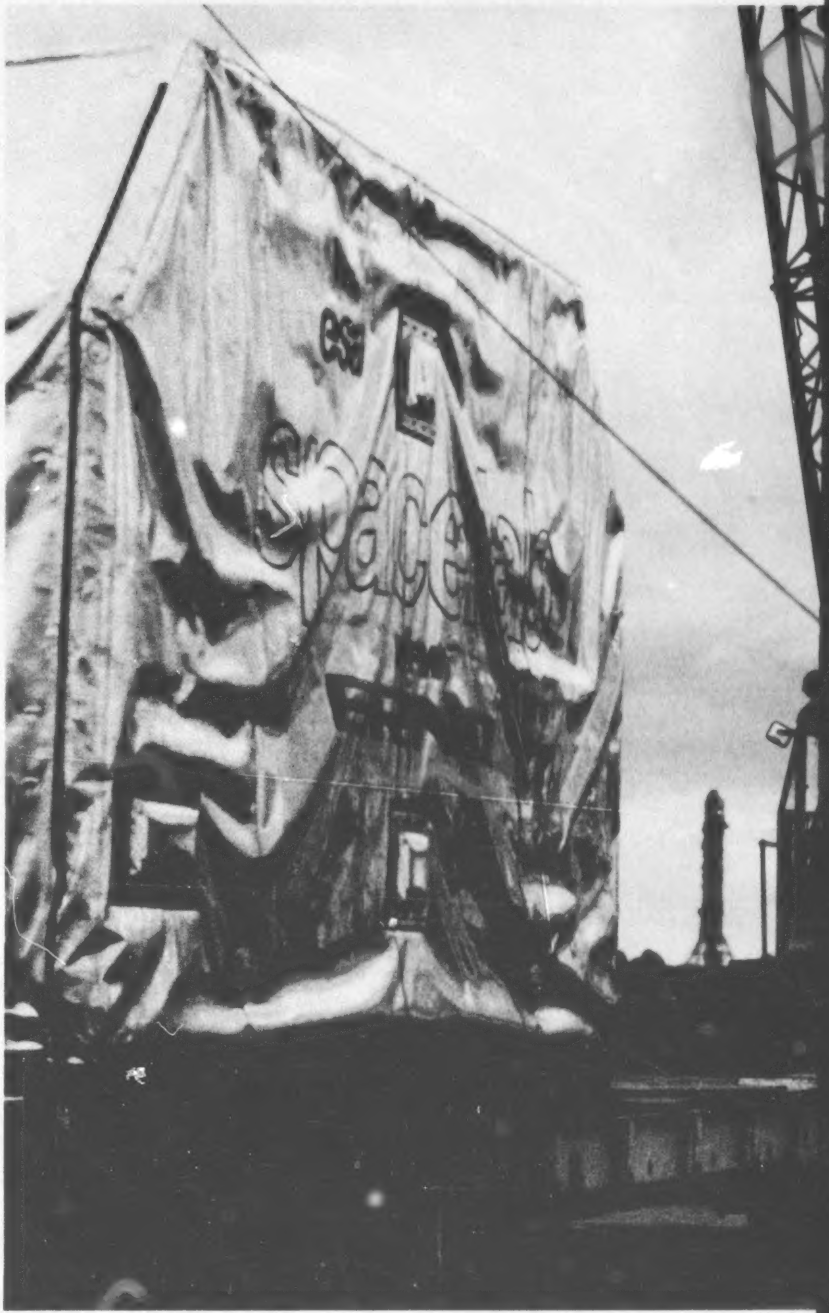
When the President's decision deferred an early start for a space station, NASA immediately modified the RAM concept to modules that would enter orbit in the Shuttle, perform their functions as a short-stay "sortie laboratory," and return to Earth at the end of the Shuttle mission.

During the American space station studies in the early 1970s, some European firms worked as subcontractors to American companies in formulating these new concepts. Through the years the United States entered nearly 1,000 agreements with almost 100 nations on space cooperation. But most covered only a single project or other joint effort, such as the United States launching another nation's satellite or carrying another nation's research instrument aboard an orbiting U.S. spacecraft. Until *Spacelab* no agreement called for such a large-scale joint development.

Europe Studies Proposals

When NASA offered Europe an opportunity to become a partner in one of the upcoming ventures, European nations responded with enthusiasm. Discussions began between representatives of NASA and the two European space agencies of that time—the European Launcher Development Organization (ELDO) and the European Space Research Organization (ESRO). Both later merged into the present European Space Agency (ESA).

Discussions over several years culminated in agreement that, rather than Europe contributing some component of America's newest delivery vehicle—the Shuttle—the United States would relinquish and European nations would accept responsibility for developing a discrete entity—a space laboratory to enhance the Shuttle's capacity for carrying out important scientific research. Furthermore, both the technology and funding required for such a sortie laboratory were well within ESA's means.



Unloading Spacelab*: Covered by protective shrouds with "ESA" and "ERNO" markings, components of the* Spacelab *engineering model arriving from Europe are unloaded from a C-5 transport airplane at the Kennedy Space Center in Florida.*

International Agreement Signed

Europeans and the United States made their decision final by signing the intergovernmental agreement in August 1973. Nine of the European partners signed at that time; Austria joined the project later. This document establishes the responsibilities of each partner and assigned implementation of the project to NASA in the United States and ESRO in Europe.

More specific and detailed statements governing the execution of the *Spacelab* program appear in another agreement signed at the same time. This is the *Spacelab* Memorandum of Understanding (MOU). The MOU was initialed on August 14, 1973, by NASA Administrator James Fletcher for the United States and by Alexander Hocker, ESRO Director-General, for the participating European nations.

Though the MOU concerned construction of a facility for research in the physical sciences in space, its signing marked the advent of a greatly expanded international technical cooperation. To work out the complex technical aspects and management procedures for this project required scores of joint meetings by American and European administrators, scientists, engineers, technicians, and other specialists—as well as by political leaders and eventually candidates for the flight crews.

A manager at NASA headquarters in Washington, D.C., recalls the cosmopolitan nature of the gatherings: "There were eleven of us with eight different mother tongues. From the outset we had all agreed that discussions and negotiations would be carried out in English. We soon discovered there were nine kinds of English—American English, 'English' English, plus the seven distinctive English accents of the representatives of the other nations." Of course the American English included some very pronounced regional accents, which frequently intrigued the Europeans.

Close Relationships Develop

Many of the participants in the meetings recall that, in the give-and-take of negotiations, respect, understanding, and even admiration and personal friendships developed among delegates of the 10 participating European nations and representatives of the United States. Europeans, accustomed to more formal relationships, adopted the practice of addressing Americans by their first names. Americans accustomed to fast cafeteria lunches came to appreciate the relaxed European midday meals.

ESA, NASA Approaches

Many potentially intractable problems arising from differing technological and administrative procedures were gradually overcome. Though *Spacelab* had to fit precisely into the Orbiter's cargo bay, and power distribution and environmental control systems had to match perfectly, the Europeans retained their metric system and the United States worked with the traditional English system of measurements throughout the project. Changing would have been prohibitively costly and would have required replacement of vast quantities of expensive measuring tools and equipment.

The MOU clearly established that the European nations would jointly design and build *Spacelab* and provide the first unit to NASA. NASA would have free use of it, but would supply system and operational requirements and Shuttle interfaces for the *Spacelab* system. NASA also was to provide technical and management advice, and, later in the project, buy a second complete *Spacelab* unit from the ESA consortium. The U.S. space agency also would manage all Shuttle-*Spacelab* flights and operate the spaceborne laboratory units. This meant providing buildings and workstands for assembling and checking out *Spacelab* components for each flight, furnishing crew training and simulators, handling payload logistics, and operating the control centers.

The first *Spacelab* flight was to be a cooperative mission. NASA and ESA would each be allowed to fly experiments of equal total weight and electric power needs. There would be a European scientist in the crew. Thereafter *Spacelab* would be available to all users on cooperative or cost-reimbursable bases.

Ordinarily ESA assigns funding quotas to each member nation based on relative gross national products. In the *Spacelab* project West Germany took the lead and contributed more than half of the funds. Each participating nation expects to receive industrial contracts closely matching its contributions to a project.

ESA Participation Apportioned

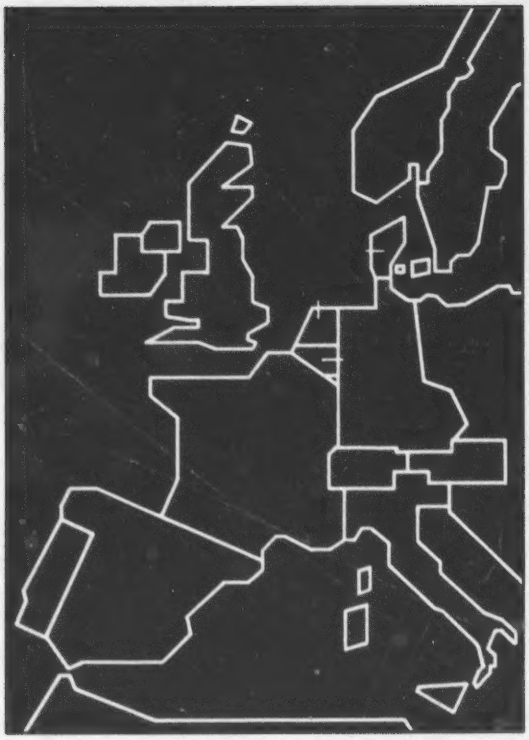
West Germany provided 53.3 percent of *Spacelab*'s cost and fulfilled 52.6 percent of all *Spacelab* work contracts. The industrial firm ERNO VFW Fokker, after submitting the winning design, became the prime contractor for *Spacelab*. At that time the company was owned by both West German and Dutch interests. Since then ERNO has been taken over by the West German firm Messerschmitt Bolkow Blohm. The ERNO plant in Bremen continued as the headquarters for *Spacelab* design, production management, component testing, and assembly.

West Germany's AEG-Telefunken provided *Spacelab*'s electric power distribution system, and Dornier Systems built the life support equipment. With 18 percent of the contributions to *Spacelab* and 13.1 percent* of the work contracts, Italy is the second largest *Spacelab* participant. Italy's industrial firm Aeritalia built the *Spacelab* module, all the racks that fit inside, and the thermal control system.

France, with 10 percent of contributions and 12.2 percent of the contracts, was assigned the avionics systems, with the firm MATRA in charge. France also provided other components, including the three *Spacelab* computers, which operate independently from the five American-built computers in the Orbiter.

The United Kingdom, with 6.3 percent of the contributions and 7.1 percent of contracts, built the pallets, including those two that flew before SL-1. Belgium (4.2 percent of contributions, 5 percent of contracts) built the electrical ground support equipment and the Igloo structure. Spain (2.8 percent of contributions, 3.9 percent of contracts) provided mechanical ground support equipment. The Netherlands (2.1 percent of contributions, 2 percent of contracts) built the scientific airlock.

Denmark (1.5 percent of contributions, 2 percent of contracts) provided part of the computer software (programming). Austria (0.8 percent of contributions, 0.5 percent of contracts) built part of the mechanical ground support equipment, and Switzerland (1 percent of contributions, 1.6 percent of contracts) built part of the electrical ground support equipment. In addition, France,



Main European Contractors

Germany
- *AEG—Telefunken*
- *Dornier Systems*
- *Draeger*
- *ERNO*
- *MBB*
- *Nord Micro*
- *SEL*
- *VFW-Fokker*

Austria
- *OKG*

Belgium
- *Bell Telephone Mfg.*
- *ETCA*
- *SABCA*

Denmark
- *Christian Rovsing*
- *Kampsax*
- *TERMA*

Spain
- *INTA*
- *SENER*

France
- *SEMS*
- *Matra*
- *Thomson-CSF*

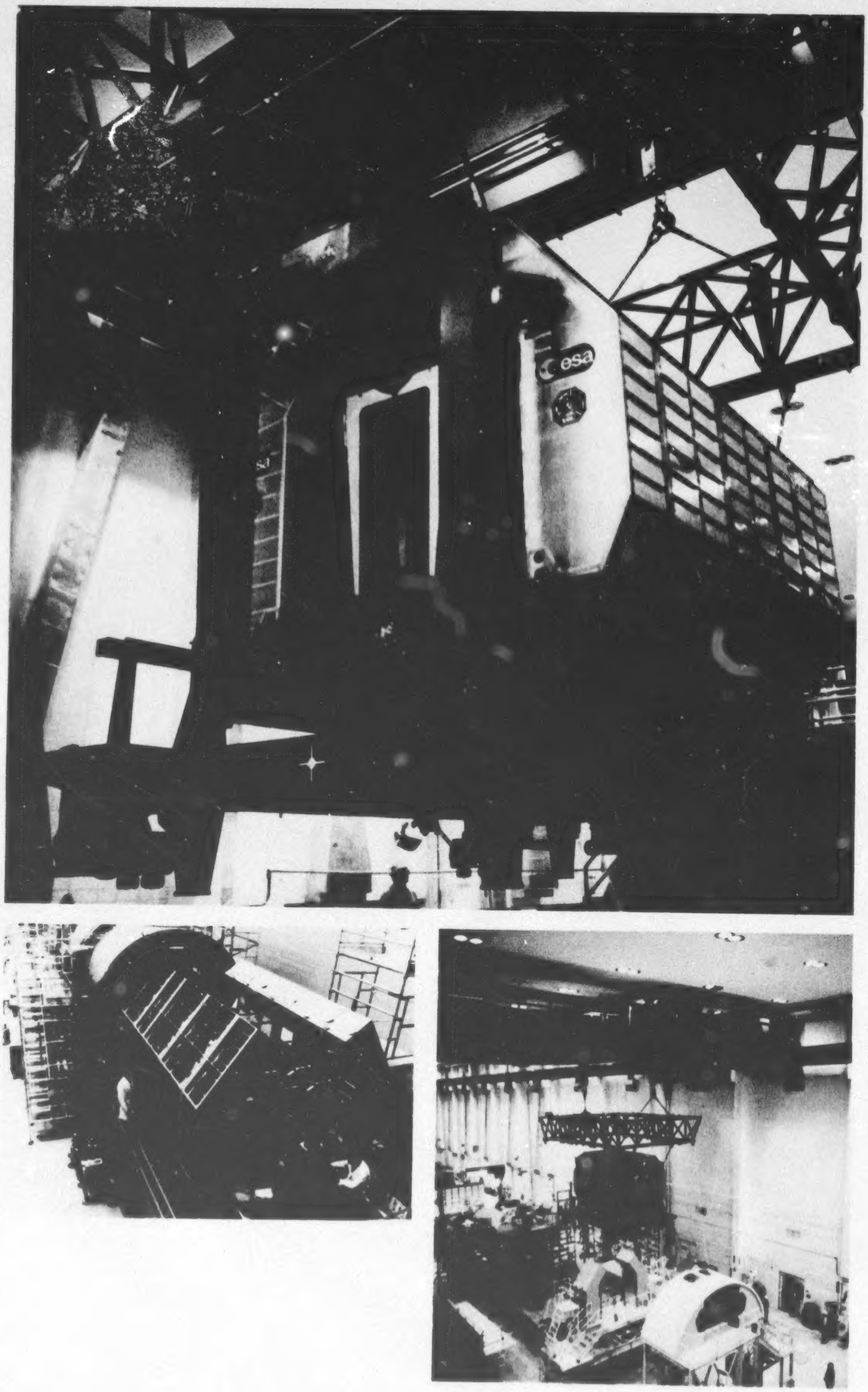
Italy
- *Aeritalia*
- *Microtecnica*

Netherlands
- *Fokker-VFW*

United Kingdom
- *British Aerospace Dynamics Group*

Switzerland
- *Compagnie Industrielle Radio-electrique*

All data on contributions and contracts furnished by ESA.



Three stages in the assembly of the Spacelab *engineering module at the* ERNO *plant in Bremen, West Germany.*

Italy, Switzerland, and the United Kingdom all made valuable contributions to the development of the Instrument Pointing System (IPS) built by Germany's Dornier Systems as prime contractor. The IPS aims *Spacelab* telescopes and other instruments with great precision.

More Than 2,000 Employed

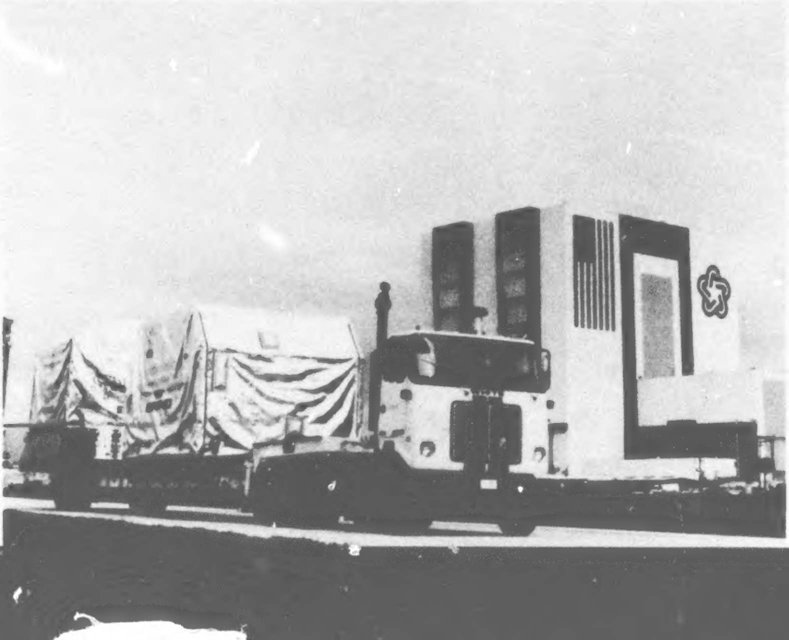
At the height of manufacturing activities more than 2,000 Europeans employed by more than 40 contractors and subcontractors in Europe were working on *Spacelab* or its component and support equipment.

The first *Spacelab* components to arrive in the United States were three "engineering model" pallets. These arrived in 1979 after they had been used in European ground tests. They were intended for use by NASA to train technicians and give them practice in mounting instruments on pallets. They were not intended for flight. However, two of them became the first *Spacelab* units to go into space when one was used on the second Shuttle flight (STS-2) in November 1981, and another on the third Shuttle flight (STS-3) in April 1982.

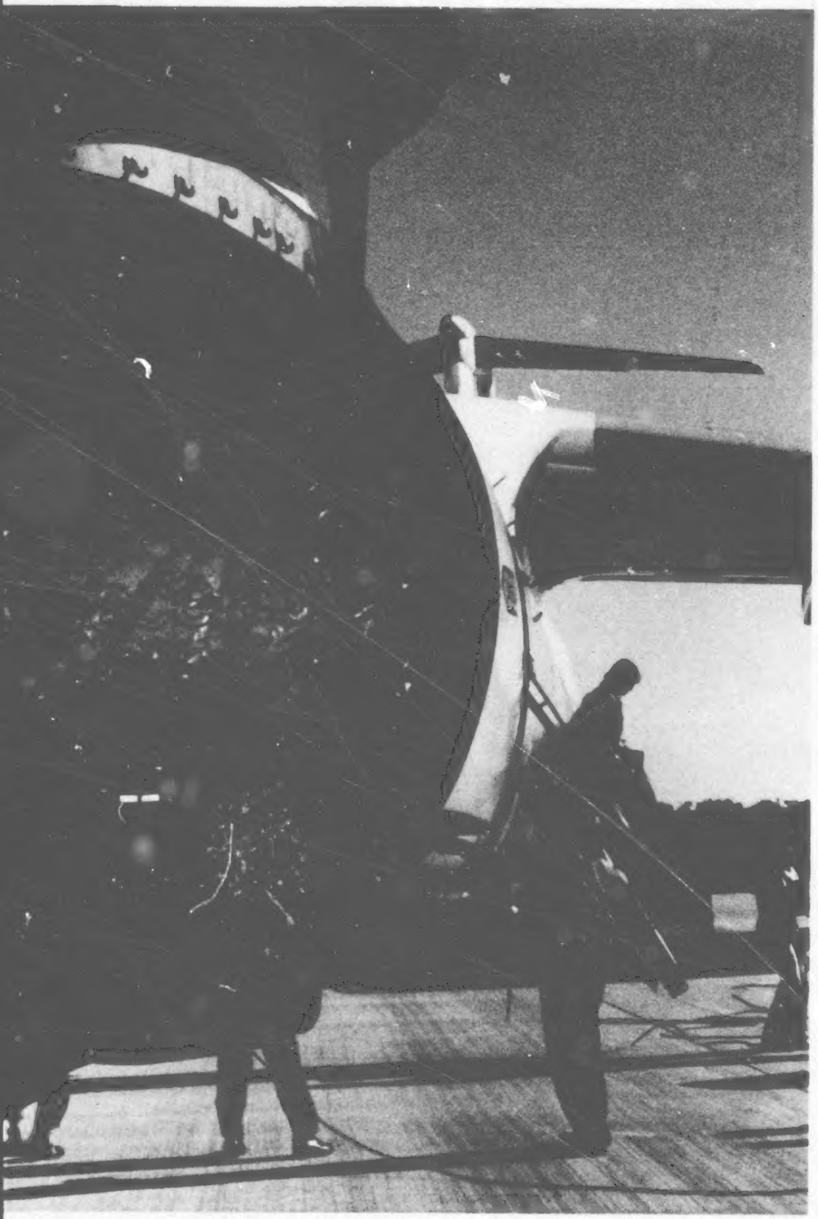
A variety of Earth observation instruments were mounted on that first pallet. Instruments to measure the space environment surrounding the Orbiter were on the second pallet. They proved that excellent scientific work could be performed on pallets.

Module Delivered

Next to arrive in the United States was the engineering model of the habitable module. As in the case of the pallets, this engineering model worked almost identically to a flight element. But it was not required to pass the tests to which flight hardware is subjected. This model was delivered from Bremen to



Spacelab*'s engineering module—a unit nearly identical with the later flight units—arrives in the United States from Europe in a large transatlantic cargo plane, and after unloading is shipped by truck to assembly and testing facilities at the Kennedy Space Center in Florida. The engineering module was used for training ground-service personnel and for testing.*



Spacelab *arrives. In a ceremony at the Kennedy Space Center in Florida on February 5, 1982,* Spacelab *was turned over by the European Space Agency (ESA) to NASA for use aboard the Shuttle. Participating in the transfer ceremony were (from left) ESA Director-General Eric Quistgaard, Vice President George Bush, NASA Administrator James M. Beggs, and Dr. Johannes Ortner, Chairman of ESA's* Spacelab *Program Board.*

the Kennedy Space Center in Florida in November 1980 and was used to train ground crews in the handling and installation of *Spacelab* components.

On February 5, 1982, in formal ceremonies at the Kennedy Space Center, the module and two pallets of the first flight unit of *Spacelab* were delivered by ESA. Acceptance of these flight articles by NASA as flight-qualified had been completed two months before in Bremen.

Echoing the thoughts and feelings of many of his fellow Europeans, ESA Director-General Erik Quistgaard told the assembled dignitaries and *Spacelab* workers from Europe and the United States at the Florida ceremonies:

"It is indeed a proud day for us Europeans. For the first time we are offering NASA an essential part for one of its space programs. Europe has, for many years, either within the framework of ESA or in multilateral projects, contributed experiments and equipment to NASA programs, but never before have we developed and built, as a joint European venture, such a major element of a NASA program. It is a great pleasure for us to hand the first flight unit (of *Spacelab*) over to NASA today."

In reply, Vice President George Bush told the European and American audience:

"We are returning to space together, and that is no small achievement. Space Shuttle and *Spacelab* represent a bond, not just of transatlantic cooperation and friendship, but of a cooperation and friendship that will extend even beyond the Earth into space."

Working Groups Formed

The Memorandum of Understanding—the basic document for the NASA-ESA collaboration on the *Spacelab* project—called for establishment of a Joint Spacelab Working Group (JSLWG). Participants pronounced the acronym "Jizzlewig." The meetings of JSLWG for management coordination between ESA and NASA are cochaired by the *Spacelab* program directors at ESA in Paris and NASA headquarters in Washington, D.C. The meetings are also regularly attended by the *Spacelab* project manager of the European Space Research and Technology Center in Noordwijk, the Netherlands, and the NASA *Spacelab* program manager at the Marshall Space Flight Center.

Experts from participating countries were invited to attend JSLWG meetings for information exchanges and consultation while the Shuttle and *Spacelab* were being built, and to help with resolution of problems that appeared during preparation for operations.

Sixteen experts from ESA and its contractors from six different countries have become members of a European Resident Team (ERT). They are living with their families near the Kennedy Space Center (KSC). This team is supplemented by ESA specialists flown in for short stays for consultation on particular aspects of their expertise. The ERT members have been making their experience available to NASA through assisting with development of methods for assembling and checking out the *Spacelab* systems and by helping to solve some of the problems that invariably arise with complex new equipment. The ERT will stay at KSC at least through the first two *Spacelab* flights.

Meanwhile, another temporary resident team of 20 experts has been supporting the Kennedy Space Center with the installation of the European research instruments to be used on board the first *Spacelab* flight.

Pallet Concept Emerges

Looking to the future, the orbiting laboratory has introduced concepts which will undoubtedly influence the design of space activities in the decades ahead. For example, the use of pallets as a new, relatively simple, and inexpensive way to perform research in orbit may catch on and expand. Eventually a variety of pallets may emerge. Some of the new pallets may be developed for commercial ventures. Industrial firms might acquire pallets for development of profitable pharmaceutical products. There may also be free-flying pallets and platforms, released into orbit and later retrieved by the Shuttle, which may record data for later analysis or transmit research results immediately by radio.

These retrievable pallets and platforms could be delivered to orbit for either long or short exposures in space and returned to Earth for reuse with Shuttle. Eventually, a resuppliable space station designed for indefinite stay in orbit could be supplemented by experiment-laden manned modules and free-flying pallets resembling those of *Spacelab*.

Much New Data Expected

Analysis and interpretation of some *Spacelab*-generated scientific data may become available quickly after each flight. Some sorting, processing, and analysis may take many months or even several years.

The vast quantities of research information emanating from *Spacelab* will provide material for scientific papers which investigators will publish in scientific journals or present at scientific meetings. Scientific papers are a tangible end product of scientific research, and *Spacelab* is expected to be the source of large quantities of them. Such papers are the means by which research results come into possession of scientists everywhere and through them become part of humankind's store of knowledge. It is from this ever-growing data base that we gain a better understanding of ourselves and our world, and greater control over our lives. As the story of *Spacelab* gradually fades into the flow of world events, it is the knowledge it generated that will give this modular laboratory its place in human history. Because knowledge lasts forever.

About the Author

Walter Froehlich is a veteran newspaper and magazine writer specializing in science and technology subjects. He operates his own news and feature service, *International Science Writers,* in Washington, D.C. He has covered the U.S. space program from its beginning 25 years ago. This is his fifth major NASA publication. He authored *Man in Space,* the first pamphlet in the NASA series on "Space in the Seventies," in 1971; *Science at Fra Mauro,* a pamphlet on Apollo 14, in 1971; *Apollo 16 at Descartes,* a pamphlet on the fifth manned Moon landing flight in 1972; and a 130-page book, *Apollo Soyuz,* in 1976.

Acknowledgments

Material for this publication was obtained through interviews and the comments and contributions of many people. Particular thanks for supplying information are due to:

James C. Harrington, Director; Robert L. Lohman, Chief Development; Alfred L. Ryan, Chief, Integration and Testing; John E. Moye, Manager, Avionics and Software Systems; and Edward James, Technical Support Manager, all of the *Spacelab* Division; and David W. Garrett, Public Affairs Officer, Office of Space Flight, NASA Headquarters, Washington, D.C.

Michael J. Sander, Director; Richard E. Halpern, Deputy Director; Mary Jo Smith, *Spacelab-1* Program Manager; and Michael J. Wiskerchen, *Spacelab-1* program scientist, all of the *Spacelab* Flight Division, Office of Space Science and Applications, NASA Headquarters, Washington, D.C.

U. John Sakss, Acting Chief, International Planning and Programs, and Debra J. Rahn, Public Affairs Officer, both of the International Affairs Division, Office of External Relations, NASA Headquarters, Washington, D.C.

Mary G. Fitzpatrick, Media Services, and Miles Waggoner, Management Services, Public Affairs Division, NASA Headquarters, Washington, D.C.

Douglas R. Lord (retired), formerly Director, *Spacelab* Division, Office of Spaceflight, NASA Headquarters, Washington, D.C.

Robert J. Freitag, Deputy Director, and William J. O'Donnell, Public Affairs Officer, both of the Space Station Task Force, NASA Headquarters, Washington, D.C.

Les Gaver, Chief, and Tony L. Ellington, Audio Visual Branch; Public Affairs Division, NASA Headquarters, Washington, D.C.

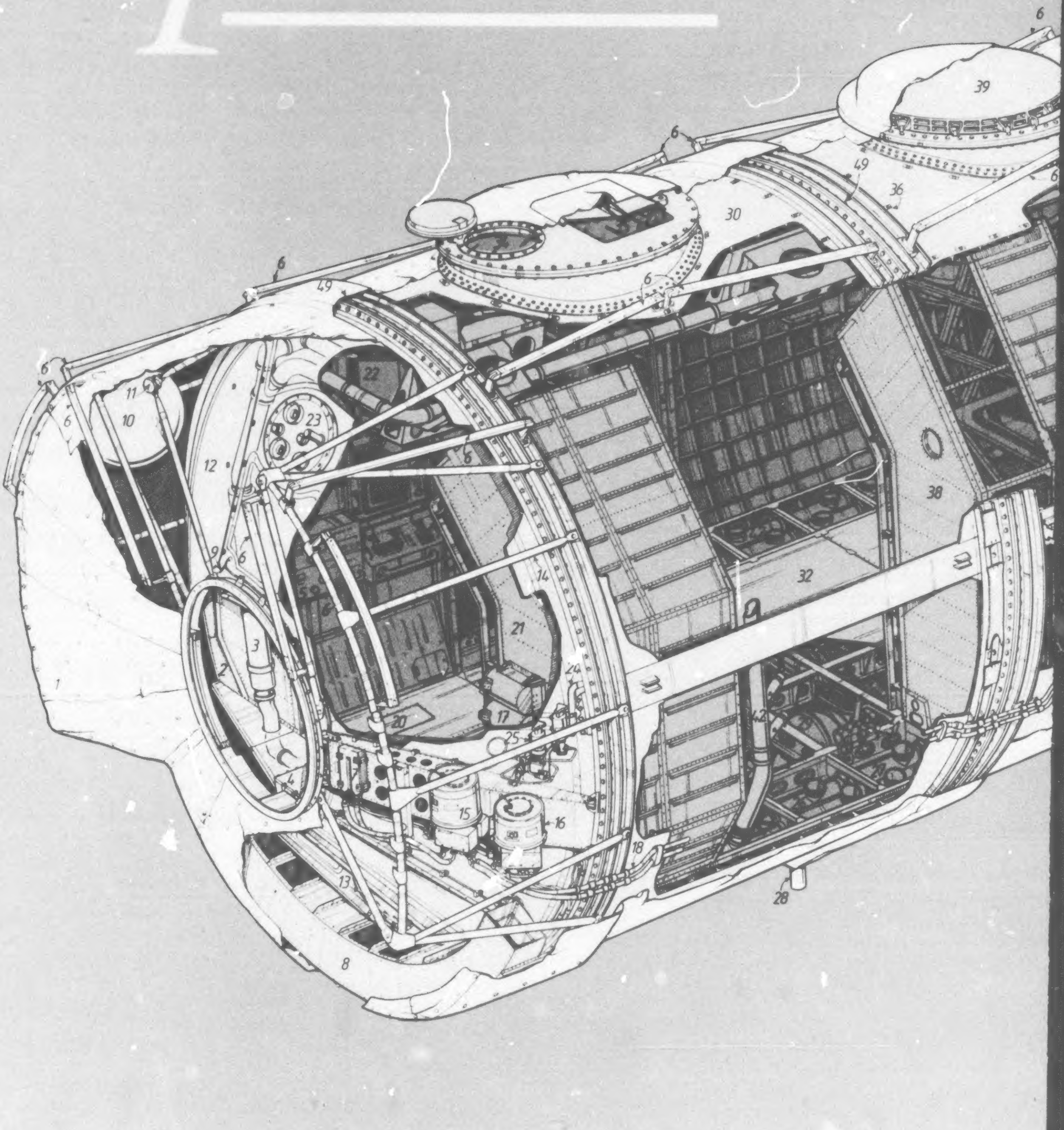
John E. Riley, Deputy Chief, Public Information Branch, Lyndon B. Johnson Space Center, Houston, Texas.

David B. Drachlis, Public Affairs Specialist and Linda Doherty both of the Public Information Branch, Marshall Space Flight Center, Huntsville, Alabama.

Ian Pryke, Deputy Manager, Washington, D.C., Office, European Space Agency.

MODULE & PALLET

Spacelab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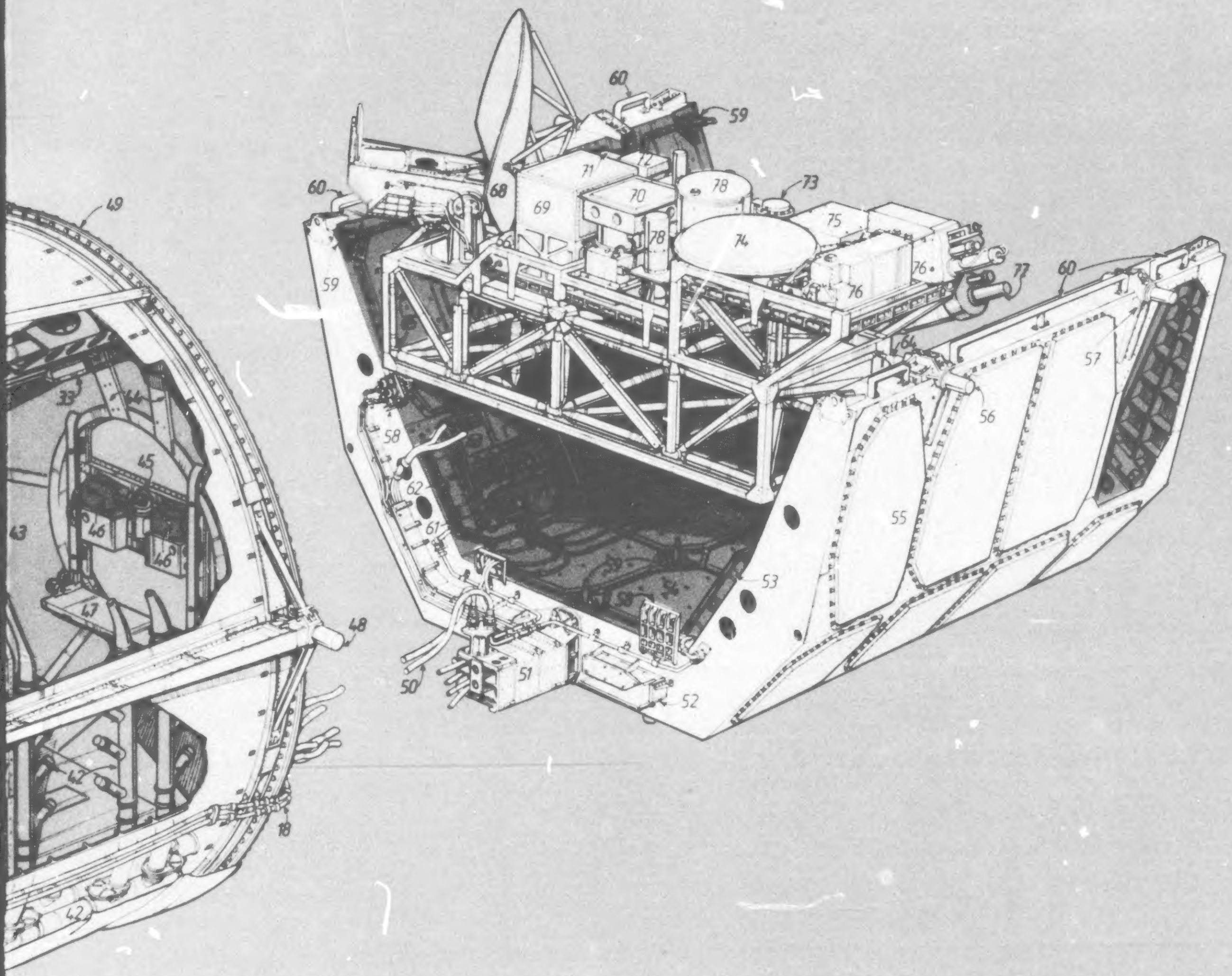

Key

MODULE

1 Insulation blanket
2 Close-outs (skin/racks)
3 Cabin air ducting (from sub-floor)
4 RAAB
5 High data-rate recorder
6 Handrails
7 Water/Freon heat exchanger
8 Utility tray
9 Gaseous nitrogen supply line
10 Gaseous nitrogen tank
11 Temperature transducer
12 Forward end-cone
13 Module/Orbiter lower feed-through plates (two)
14 Insulation blanket supports
15 Freon pump
16 Water pump
17 Lithium Hydroxide cartridge stowage
18 Freon lines
19 Control-centre rack
20 Debris traps
21 Workbench rack
22 Stowage container (lowers for access)
23 Upper module/Orbiter feed-through plate
24 Gaseous nitrogen fill-valve bracket
25 Gaseous nitrogen reducing valves (two-stage)
26 Position for double rack
27 Position for single rack
28 Keel fitting
29 Sub-floor
30 Aluminium alloy module shell
31 Electrical connectors for rack
32 Floor of aluminium-skinned honey-comb sandwich (centre panel fixed, outer panels hinge up for access)
33 Overhead duct channels
34 Viewport
35 NASA high-quality window
36 Fasteners for insulation blanket
37 Rack fire-suppression system
38 Double rack
39 Experiment airlock
40 Airlock controls
41 Overhead lights
42 Avionics cooling-air ducts
43 Aft end-cone
44 Radial support structure
45 Fire extinguisher (Halon)
46 Portable oxygen equipment
47 Foot restraint
48 Module/Orbiter pickups (four)
49 Module-segments joints, incorporating seals

PALLET

50 Freon lines from Module
51 Pallet interface
52 Cable ducts
53 Cold plates
54 Inner skin-panels
55 Outer skin-panels
56 Pallet/Orbiter primary pickup
57 Pallet/Orbiter stabiliser pickup
58 Connector supports
59 Pallet hard-points
60 Handrails
61 Support systems Remote Acquisition Unit (RAU)
62 Experiment RAU (several)
63 Experiment power distribution box
64 Pallet/bridge supports
65 Experiment-supporting bridge
66 Electrical junction box
67 Integrally-machined aluminium-alloy ribs

EXPERIMENTS*

68 Synthetic aperture radar
69 Solar spectrum
70 X-ray astronomy
71 Solar constant
72 Charged-particle beam
73 Advanced biostack
74 Isotopic stack
75 Micro-organisms
76 Lyman Alpha
77 Waves
78 Low energy electron-flux

**Representative Experiments*

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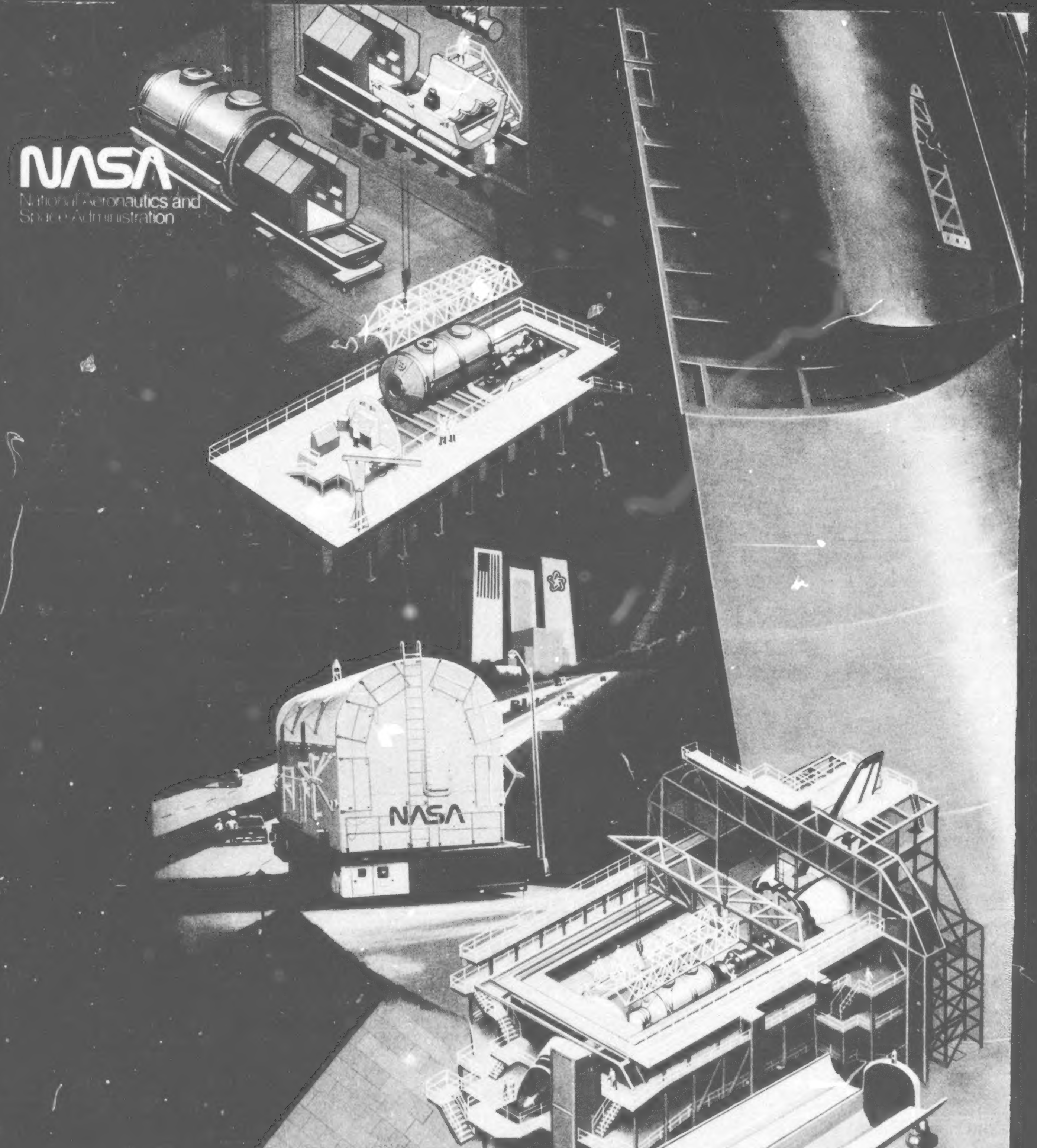

National Aeronautics and
Space Administration

25
Twenty-fifth Anniversary
1958-1983